INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND FIRST GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, W.C., on Tuesday evening, April 12th, 1927, Sir Frederick Black, K.C.B. (Past-President), in the Chair.

The Chairman, at the opening of the meeting, apologised for the absence of the President, Mr. Alfred C. Adams.

It would be interesting to the members to know that the two branches of the Institution which had been formed in Rumania and in Persia were both in actual working order. He was sure the members would agree that that was a very good beginning, and it was to be hoped that the formation of branches in two such important centres would be followed in other districts.

The following paper was then read :—

"Jet and Jetonised Material."

By E. H. CUNNINGHAM CRAIG, B.A., F.R.S.E., F.G.S., (Member).

1. THIS investigation is a continuation of, and supplementary to, the writer's former papers upon oil shales, torbanites and cannel coals. The subject is approached from the practical side, *i.e.*, regarding these deposits as retortable material from which oil can be obtained in commercial quantity. The results of many retorting tests made upon a large scale have made it clear that the usual analysis giving percentages of volatile matter, fixed-carbon, ash and water does not necessarily give an adequate criterion from which the value of a given material, or the nature of the oil to be derived from it, can be determined. This applies particularly to coaly deposits, such as parrots, cannels, torbanites, lignites, and even true coals. The results of the investigation so far have opened up such a wide field for research that it cannot be pretended that anything like complete information has been obtained. However, as some facts of a practical value have come to light, bearing upon retorting problems, it was considered advisable to put before this Institution a brief account of the line of research followed, as well as some of the results and the deductions that appear to follow from them. Much further work along the same or similar lines will be necessary, and the co-operation of a chemist is desirable to enable the full fruits of such an experimental investigation to be gathered.

It has been shown that in the case of torbanites the yield of oil is directly proportional to the percentage of gels in the deposit and

the degree of inspissation which those gels have suffered. A microscopic study of a torbanite, therefore, which enables the percentage of gels to be measured and their stage of deterioration noted, gives sufficient data to predict with reasonable accuracy the yield of oil in gallons per ton by a known retorting process, and the nature of the oil, whether light and mobile or heavy and waxy.

But when we deal with torbanitic cannels—most cannels have some torbanitic development—the matter becomes more complicated as the gels play a smaller part and the matrix a proportionally greater part. The nature of the matrix thus becomes the predominant factor. In a normal torbanite the matrix has reached the coal stage, and is often quite dense and black, but cannels in most cases have not been so much affected, and the matrix is frequently a deep or even a reddish brown, thus approximating to the lignitic stage. Cannels, moreover, usually contain a far larger proportion of recognisable vegetable debris than true coals, and this debris is frequently in what has been called the "jetonised" state, *i.e.*, resembling jet.

The term "jetonised," so far as I have been able to ascertain, means that the vegetable shape is retained, though no doubt somewhat flattened by pressure, but not the vegetable structures.

The present investigation was commenced with the view of studying this jetonised condition, of ascertaining whether it is a definite stage in the formation of coal, and what is its value or significance in connection with retorting problems.

2. The first material to be examined was naturally the type mineral, jet. This substance is very well known, but there seems to have been very little research work done upon it. It occurs included in or associated with lignitic beds, and in some cases can be proved to have never been subjected to very high pressures. It has a hackly or subconchoidal fracture, a bright lustre, and appears to be almost perfectly homogeneous. The specific gravity is low, 1·17—1·230. All jet that the writer has been able to obtain is of Jurassic or Cretaceous age. Somewhat similar material of Tertiary age is known, but is not considered as true jet. It is sometimes described as bituminous, but on what grounds seems to be doubtful. It does not melt when heated, nor is it soluble to any appreciable extent in solvents for bitumen. It burns easily and intumesces very slightly while burning. Extracted with boiling carbon disulphide, it loses weight to the extent of only 4·4 per cent., and the larger proportion of this is probably water. This does not indicate a bituminous nature.

Examined under the microscope, it is seen that, contrary to what seems to have been the general belief, vegetable structures have not been obliterated.

Figure 1 is a section of a piece of jet from Oles, in Asturias, Spain. It shows very distinctly vegetable structures, though they are much flattened and in the process of becoming obliterated. The dark rays and patches are apparently medullary rays along which a darker material has been injected or segregated. The specimen is obviously solid wood, as is indicated by the hand specimen, which is flattened to one-third or one-quarter its original thickness. The wood is probably that of a conifer, and the darker material may be resinous, though on this point there is some doubt. Resin usually appears a very pale yellow under the microscope, and the behaviour

FIG. 1.

SPANISH JET.

(Showing traces of cells.)

of the material when burnt or when retorted does not suggest a resinous so much as a waxy nature. Between the medullary rays the traces of cells, more or less destroyed, can be detected. The specific gravity is very high for jet, 1·230.

Figure 2 is a section of Whitby jet. In this the original structures are still more obscured. The darker material stands out rather more clearly, and is segregated into well-defined rounded patches and streaks. It is of a dark dull brown colour, contrasting much more clearly with the matrix than in Figure 1. All traces of cells have disappeared. The specific gravity is 1·180.

Figure 3, also of Whitby jet, seems to show an even later stage. The traces of medullary rays are still clear, but there seems to have been a distinct segregation of the darker material, and the traces of rays die out here and there. Still it cannot be said that original structures have been by any means obliterated, though the mass of the material is becoming more nearly homogeneous.

These figures prove quite conclusively what jet has been originally —it was wood from the heart of a tree trunk, branch or root. The colour under the microscope varies, according to the thickness of the slide, from a bright yellow to a bright red brown, very similar to the colours of a rich oil shale.

FIG. 2.
WHITBY JET.

The point to be observed is that jet is in much the same physical state as we see in many lignites; it has been wood, but has undergone no doubt various chemical changes, so much so that it appears

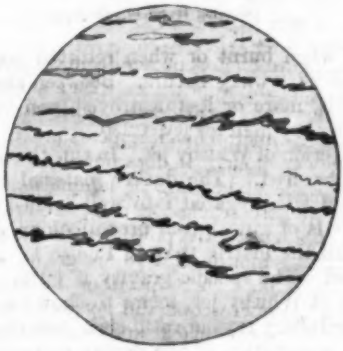

FIG. 3.
WHITBY JET.
(Rays beginning to disappear.)

at first sight to be homogeneous, has lost its woody fracture, and is capable of taking a very high polish. There are indications that it may have been plastic at some stage.

Treated in the Struben still, a description of the working of which will, it is to be hoped, soon be given to this Institution, jet gives very remarkable results. It is found to contain 8 per cent. of water, 3 per cent. of which comes off at just above 100° C., while the remaining 5 per cent. is distilled over at temperatures between 160° and 250° C. Nineteen per cent. of the weight of the original material comes off as a light oil (·792 sp. gr.) no doubt containing acids and other impurities. This oil is slightly sulphurous. This distillate comes off at temperatures below 300° C. In addition to this heavy waxy oils appear, but these chiefly come over at temperatures between 300° and 320° C. The total yield of oil and waxes, apart from water, is at the rate of 57·8 gallons per ton. This is a very remarkable result, and indicates that the material is obviously much changed from its original condition. In fact the jetonised condition, if we can recognise it as a definite condition, is seen to be of importance from the point of view of retorting for the extraction of oils and waxes. The original wood has lost water and presumably also oxygen in the form of carbon dioxide. It must have a fairly low carbon-hydrogen ratio, judging from the quantity and quality of the oil produced. In fact it shows a marked advance from the wood stage toward the oil producing stage, that is, oil producing by what has been called pyrogenesis.

To learn something more about the jetonised condition, and more especially to ascertain whether it can be recognised as a definite stage, a few specimens have been selected from a very large number of lignitic and canneloid deposits, and subjected to special examination and testing.

The first is a lignite of Eocene age from Sumatra. It is a bright clean lignite of canneloid appearance with a subconchoidal fracture, black in colour, but occasionally with an iridescent bloom. Examined under the microscope it appears practically homogeneous, of a rich red-brown colour. It does not show vegetable structures, and very little trace of bedding or lamination, and therefore the deposit has apparently reached a more advanced stage than jet. A specimen of this lignite was powdered finely and introduced in a solution of calcium chloride of 1·18 sp. gr., a portion floated, and nearly as much sank. These portions filtered off, washed and examined under the microscope, did not differ very much in visible character: both appear black and amorphous, but the larger fragments are transparent on thin edges, and of a bright brown colour. The "floats" appear somewhat blacker than the "sinks." This material was not extracted with carbon disulphide, but was

treated with boiling kerosene at a temperature of 190° C., with the result that there was a loss of 5 per cent. in the weight of the lighter portion and of 1·7 per cent. of the heavier, as against 7·7 per cent. in the case of jet. It is probable that the decrease in weight was partly water, but the material, though still of nearly the same specific gravity as jet, has obviously reached a slightly further stage in mineralisation.

The next material to be examined was a lignitic coal from Kyune Canyon, Colorado, of Green River age (Eocene-Cretaceous). This deposit is well laminated, with a hackly fracture. It is quite black, and in fact appears to be a true coal. Cut for the microscope (Fig. 4), it appears of a deep red-brown colour, slightly darker than the Sumatra lignite. Lamination is well marked, but there are no identifiable vegetable structures, though faint streaks and ill defined lenticles of slightly lighter or darker tints indicate that

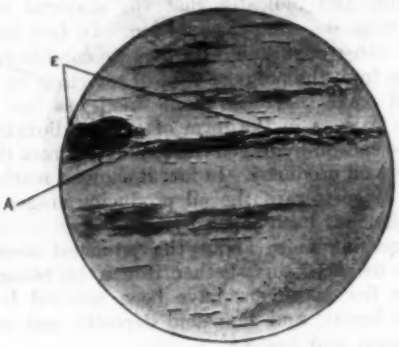

FIG. 4.

LIGNITE FROM COLORADO.

(Showing approach to coal stage.)

(a) A quartz grain. (b) Material that is practically a true coal.

the deposit has been built up of masses of fine vegetable debris. There are some darker but not very clearly defined bands that are practically black, *i.e.*, more highly carbonised, and in what may be called the coal stage. There is also a very small percentage of inorganic matter such as quartz. The specific gravity of the deposit is 1·275. When reduced to powder it floats entirely in a 1·38 solution and sinks in a 1·20 specific gravity solution, but it was found impossible to make a good separation into two different classes of material. The blacker portion is slightly heavier, but very little could be separated from the bulk of the specimen. No

extraction with carbon disulphide was attempted with this material, but extraction with boiling kerosene at 190° C. removed 9·8 per cent. In this case very little of the extracted material can be water, as the deposit is much more nearly in the stage of true coal. The deposit has been completely "jetonised," but has reached a further stage in carbonisation, as shown by the almost black bands. At the same time the hackly fracture replaces the semi-conchoidal.

The next material to be examined is a seam of cannel from the Karroo System of S. Africa, *i.e.*, of Triassic age. It occurs on the farm of Waihoek, in the Transvaal, and the geological horizon is not far from that of some of the torbanite seams. It is a black flaggy cannel with semi-conchoidal fracture and bright lustre. Lamination is distinct. This deposit being of much greater age than the deposits previously dealt with, and having been under

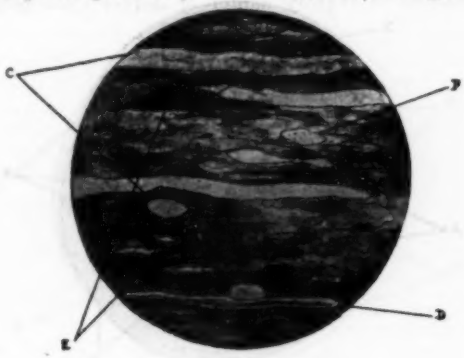

FIG. 5.

CANNEL FROM THE TRANSVAAL.

(*b*) Torbanite gel.
(*c*) Jetonised wood.
(*d*) Section of macrospore.
(*e*) Parts of matrix that have reached the coal stage.

much greater pressure, might be expected to exhibit certain points of difference. Its specific gravity is 1·37.

Cut for the microscope (Figs. 5 and 6) it is seen that the matrix is composed of material almost entirely in the jetonised condition, but the colour of the material is darker for the most part, a deep red-brown. There are small patches that are practically black, having reached the stage of a true coal. There are macrospores of a bright yellowish brown in colour, and large fragments of vegetable matter which has lost all organic structure. Inorganic matter in the form of rounded and subangular grains, chiefly quartz, are observed here and there. But the most important point to be noted is that there is a slight torbanitic development, shown in

small, rather irregular and lenticular gels. These are distinguished by their pale colour, characteristic slightly mottled appearance, and the fact that they do not disturb the lamination as do the vegetable remains. There are numbers of pale yellow streaks following the lamination; these are too small and thin for determination, they may represent incipient torbanitic development or they may be resinous matter or fragments of spore cases.

It is evident that this deposit represents a stage more advanced than the last, the Kyune Canyon lignitic coal, and the oil forming stage has actually just been reached, as proved by the formation of gels. It is quite possible that were more colloidal inorganic matter present, there would be a much greater development of gels.

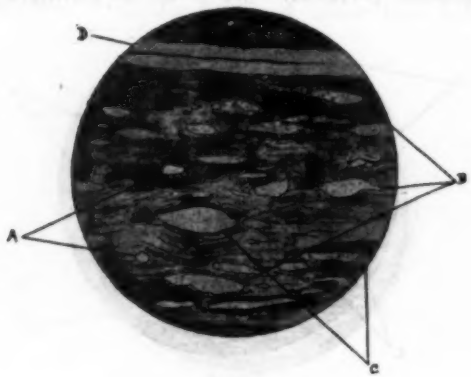

FIG. 6.

CANNEL FROM THE TRANSVAAL.

(*a*) Grains of quartz.
(*b*) Torbanitic gels.
(*c*) Jetonised wood.
(*d*) Part of a macrospore.

The constituents of this cannel being chiefly in the same condition a separation by flotation into different portions was not easy. Practically all the material when powdered floats in a 1·38 sp. gr. solution, and nearly all sinks in a 1·20 solution. The material that floats in a 1·25 solution gives a percentage of 4·7 soluble in boiling kerosene (190° C.), while the portion that sinks gives 1·9 per cent. soluble in carbon disulphide, and 9·7 per cent. soluble in boiling kerosene. The light portion seems to be almost entirely torbanite gels, with possibly some fine particles of waxy or resinous material.

Retorted by a low temperature method, this cannel yields 40

gallons of oil to the ton, and the oil is of fairly good quality. Some tests made at higher temperatures did not give such good results.

The next material selected for examination is a well known and rich cannel, which occurs in the Jewell Seam of Midlothian. This, being of still greater age and having been subjected to high pressure and considerable earth movement, naturally shows a still more advanced stage. It is a very compact black cannel, with a fairly bright lustre and a dark brown streak. The specific gravity is 1·215.

Under the microscope (Fig. 7) the deposit is seen to be very fine grained. The matrix is very dark brown, almost that of a true coal, but small fragments of dark brown jetonised material are numerous, and what might be called the "ghosts" of other minute fragments of vegetable matter are very frequent. Most

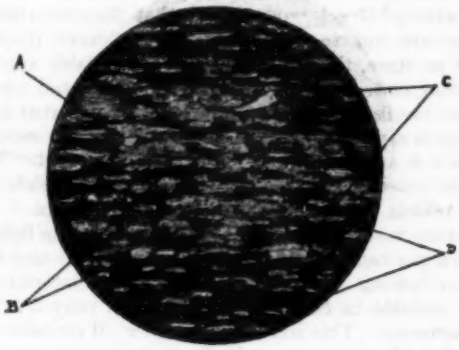

FIG. 7.

CANNEL FROM THE JEWEL SEAM, MIDLOTHIAN.

(a) Grain of quartz.
(b) Torbanite gels.
(c) Jetonised wood.
(d) Microspores.

of these are fragments of spore-cases, and they form a large part of the deposit, often shading off almost imperceptibly into the matrix. Small grains of quartz are fairly common, and are not particularly well rounded. There is a very distinct torbanitic development, but the gels are very small.

A solution of 1·19 sp. gr. makes a good separation of the powdered material, the floats, consisting chiefly of jetonised material, all of which, however, appears almost black, and some torbanite gels which are bright yellow and unfractured. It is an interesting point that the gels are much larger than the rest of the powdered material, their toughness having prevented them from crushing.

The sinks consist of inorganic matter, and black coaly material that shows no sign of structure.

No extraction tests have been made with this material, as it did not appear likely to give very definite results. We have, however, many retorting tests of the seam, since it was much used in gas works at one time, and is still used to some extent. Retorted by a low temperature method at Chiswick, this cannel yielded 47·5 gallons of oil per ton; tested later by an improved method, it gave 55 gallons. This high yield is due partly to the torbanite development, but chiefly to the fact that it is so largely formed of spore material.

It was thought advisable to compare the above materials with a well-known torbanite, and for this purpose a specimen from New South Wales was selected. It is very rich material, with a rough but semi-conchoidal fracture, and a yellow streak. It is composed almost entirely of gels, so much so that they interfere with each other and are apt to anastomose. They have frequently been described as algae, though showing no identifiable vegetable structures. What matrix there is is black and coaly, and a few inorganic grains can be distinguished. Powdered and floated in a brine of 1·28 sp. gr. a separation can be made, the floats consisting entirely of gels, which are clean and very seldom fractured. The material that sinks consists also largely of gels not completely separated from the matrix, inorganic matter and coaly matrix.

Extraction tests gave remarkable results. The lighter material yielded 5·6 per cent. soluble in carbon disulphide and 6·3 per cent. soluble in boiling kerosene. The heavier material yielded 8·1 per cent. soluble in carbon disulphide and only 3·2 per cent. in boiling kerosene. This indicates a higher oil content in the floats and a higher bitumen content in the sinks.

It may be remarked that gels separated out similarly from a Nova Scotian torbanite gave 4·4 per cent. and 7 per cent. soluble respectively, a very similar result to that given by jet. In this case the gels are very large and fresh, similar to those examined and described by Professor A. E. Flynn.

Tabulating the extraction results we have :—

	Soluble in CS_2.	Soluble in kerosene (190° C.).
Jet	4·4 ..	7·7
Lignite (Sumatra), "floats"	— ..	5·0
" " "sinks"	— ..	1·7
Lignitic coal (Kyune Canyon)	— ..	9·8
Waihoek cannel, "floats"	— ..	4·7
" " "sinks"	1·9 ..	9·7
Torbanite (N.S.W.), "floats"	5·6 ..	6·3
" " "sinks"	8·1 ..	3·2
" Nova Scotia	4·4 ..	7·0

Extractions were made with kerosene for a definite reason, i.e., to learn whether the deposits contained anything that could be called free oil. The results show that even in the case of torbanites the effect was very slight. In the cases of the jet and the Sumatra lignite a percentage of water probably not more than 3 must be allowed for; in the other cases the percentages of moisture or water are negligible.

The fact that rich material like torbanite is hardly attacked more than the jetonised portion of cannels and lignites, and in fact is less attacked by the kerosene, is very significant. It shows first of all that the gels of a torbanite resist solvents very successfully, and secondly it certainly indicates that in jetonised material there are compounds akin to petroleum. We may perhaps be premature in suggesting that hydrocarbons have been formed in these bodies, but that seems at least to be quite possible.

To sum up what has been learnt about jetonised material, it is evident that it represents an intermediate stage between wood or other vegetable matter and coal, and also we may say an intermediate stage between vegetable matter and petroleum. It is, however, not a very definite stage, since the changes it undergoes are progressive. The range shown by coals, from lignite to anthracite, is, of course, very much greater.

Jetonised material has a specific gravity of from 1·18 to 1·28; above that it approaches nearly to true coal. Chemical changes have undoubtedly taken place through time, earth temperature and, most important of all, earth pressure. During such changes, water is undoubtedly lost, and oxygen, probably in the form of carbon dioxide. But the carbon-hydrogen ratio is still fairly low, less than in normal coals.

From the data furnished above it seems we can learn something about the formation of petroleum. It is often hinted, if not definitely stated, that petroleum may begin to be formed, possibly through bacterial action, not long after the raw materials from which it is formed have accumulated and been deposited in strata. Such a theory, as has been pointed out many times, is not supported by geological evidence, all of which goes to show that high pressures are required before oil can be formed, and these high pressures can only be attained by the burying of the raw materials beneath great thicknesses of strata, indicating that much time must elapse before the requisite conditions can be said to be present.

We have seen that jet and jetonised vegetable matter can be looked upon as a more or less definite stage on the way to the formation of petroleum. In Tertiary lignites and even jet of Cretaceous and Jurassic age, though its chemical composition may be approximating to hydrocarbons, no actual formation of petro-

leum has occurred, but in older deposits such as cannels of Triassic and Carboniferous age, so long as the jetonised stage is still in evidence, something of the nature of petroleum can be formed, as proved by the development of torbanitic gels. These gels, of course, are only formed and fixed by the presence of colloidal inorganic matter, and they can only be considered as a restricted attempt to form petroleum. But still they are definite evidence of the development of hydrocarbons, and are thus distinct from coal formation. In areas characterised by the presence of numerous torbanitic seams, e.g., North Staffordshire, seepages of true petroleum frequently occur at lower horizons, though the bulk of the vegetable matter has reached the coal stage. The inference is that efficient sealing and high pressure are first essentials for the formation of petroleum, as well as sufficient raw material, in a condition far removed from its original state, but still not yet approaching the coal stage. And it is obvious that vast periods of time may be required between deposition and the time when the requisite conditions are attained.

This would also cast some doubt upon the necessity of bacterial action, which has been so often suggested as being a potent factor in the origin of petroleum. Perhaps bacteria of unspecified nature have been made responsible for rather more important effects than they are capable of causing, and in any case their various activities in oil formation are more in the realm of speculation than in that of fact.

It is aerobic bacteria that cause the decay of wood, but if the wood be deposited in a waterlogged area, the aerobic bacteria cannot function, with the result that the wood is preserved. It has been seen that in jet, lignites and jetonised material the wood has certainly been preserved from decay, and yet not prevented from changing in chemical composition in the direction that would enable it to become the raw material from which petroleum could be formed. It is difficult to conceive of bacteria attacking such jetonised material buried beneath thousands of feet of sedimentary strata and sealed in a natural autoclave. Yet the evidence all points to the probability of petroleum having been formed under these conditions.

Turning to practical questions, it has been shown that jet, though it has hardly reached the theoretical jetonised condition—that is to say, vegetable structures have not been entirely obliterated—yields as much as 57·8 gallons of oil per ton. Lignites in which vegetable structures have practically disappeared yield upwards of 50 gallons per ton, though they are not as pure material as jet. The oils, of course, contain acids and other impurities. Jetonised material in a further advanced state certainly contributes largely

to the oil yield obtained from many canneloid deposits, the nature of the original material having probably a considerable effect upon the actual yield. Thus waxy spore cases and spore material generally seems to give a better yield than woody substance, the yield from Tasmanite, a spore coal, being a case in point.

There is thus a practical application of what must be regarded as the somewhat meagre results obtained so far in this investigation. In considering raw material for retorting purposes, whether it be coal, cannel or lignite, the proportion of jetonised material, and the stage it has reached, must be noted. While the gels of a torbanite, if fresh, will yield anything up to 180 gallons per ton—the theoretical yield is even greater—jetonised material can be counted on for 40 or 50 gallons per ton.

A microscopic examination enables the percentages of torbanite gels and jetonised material to be estimated with considerable accuracy, and from these percentages the yield of oil by any known process of retorting can be calculated without any serious error. The usual analysis into moisture, volatile matter, fixed carbon and ash, may give quite a misleading idea of the value of the particular deposit as a source of oil.

The extraction of montan wax from lignites, and probably also from certain cannels, is another subject upon which it seems probable that much can be learnt by a study of jetonised material, but this must be left for a future communication. Since montan wax is of a value equal to that of rubber, the subject is important commercially.

Finally, it must again be emphasised that there is still much research work to be done before complete results can be given: the author has for a number of years been impressed by the necessity of obtaining oil and waxes from materials indigenous to this country, and it is with a view to stimulating research of this nature that he has ventured to put before this Institution what must only be considered an account of the first steps in the investigation of jetonised material.

My thanks are due to Dr. A. C. Dunningham, who has made a number of extraction tests for me, and to Mr. Wilfred N. Edwards, of the Natural History Museum, for a specimen of Spanish jet as well as for valuable suggestions.

DISCUSSION.

The Chairman said that in opening the discussion he desired to ask the author to deal with one or two points that were more of an economic than a technical nature. In the paper the author had obviously added to the valuable information he had presented to the Institution on several occasions in regard to solid retortable

materials. So far as the present paper was concerned, he was not quite clear what the term "jetonised material" exactly covered, whether, for instance, it covered all the torbanites, cannels and other materials that were referred to by the lecturer. The statement was made at the commencement of the paper: "The subject is approached from the practical side, i.e., regarding these deposits as retortable material from which oil can be obtained in commercial quantity." He could not quite follow whether, speaking of jet first of all by itself, there were large commercial quantities of jet in existence or not. The author had placed before the members two other points of view. He had called the particular material to which he referred a sort of railway junction between coal and petroleum, and had shown that valuable information as to the formation of petroleum could be obtained from experiments with jetonised material. The lecturer had also indicated rather briefly that in regard to "processes" there was a good deal to be learned from dealing with materials of that kind. On the latter point, which was perhaps the most important of all, he hoped the author would give further information to the members on a future occasion. The author had also referred to the amount of oil that was obtainable from jet and jetonised material, the number of gallons produced varying between 40 and 60 gal. per ton according to the different material used. Perhaps he was asking for a little too much information if he inquired what kind of residues, if any, were obtainable by the use of a low-temperature process. In speaking of the material as being nearer to coal than to shale, the author had given the impression that there would be perhaps "residues" as from coal. If a visit were paid to the great shale works in Scotland immense mounds of what were called "spent material" could be seen. That material was valuable only for road-making or something of that sort, but inasmuch as the author had said that jetonised material was nearer to coal than to shale he hoped he would be able to supply further information in regard to the residues. The point he wished prominently to bring forward was whether jet and jetonised material would add very much to the possible sources of the supply of oil in those days—which they all hoped were far distant—when natural petroleum began to fall off in quantity.

Dr. Arthur Haydon said that he desired to draw attention to the fact that many years ago when he was in Japan he noticed, particularly while the ship in which he was travelling was coaling at Nagasaki, a peculiar variety of Japanese coal, which was very light in character and left no black mark on the hand when touched, was placed on board. He had been wondering whether that might not be some kind of jetonised material and whether it would

contain any large percentage of oil. He would like to know whether any of the Japanese coal from Nagasaki had ever been examined microscopically or analysed. He hoped the author would send for a specimen of that Japanese coal for the purpose of examining it and ascertaining what its exact nature was as he considered that it might be of some geological interest. He knew that a very much larger quantity of such coal was required than of English coal.

Dr. Arthur Wade desired to compliment the author on what he considered to be a very valuable contribution which had bearings upon the origin of petroleum. There were a few points in the very interesting paper to which he desired to refer. In the first place, he had been very much interested in what was said in regard to the distillation of jet. Apparently the author obtained a very light oil with a specific gravity of about 0·79, while a certain amount of wax also was obtained before the coking stage was reached. Those were interesting results because they were similar to those obtained in New Guinea from rather shallow oil wells. Drilling in New Guinea in Tertiary beds at a depth of about 180 ft. a very remarkable light oil was found. The formation was estuarine in origin with a good deal of lignitic material in places. The very light oil (S.G. about 0·79) produced in those wells, when cooled to a temperature of about 40 or 50° F., deposited a considerable quantity of wax. Some waxy material was also found in porous beds which were outcropping at the surface. It seemed to him that those light, shallow oils of New Guinea could represent a stage in what might be called the metamorphism of the products in which petroleum instead of jet had been formed in the beds, the materials containing sufficient colloidal matter to form petroleum instead of jet. Probably such researches as those conducted by the author would throw a light on problems of that kind. If he was correct, probably very large quantities of oil of that character would not be obtained, as the result was due to local and favourable conditions in shallow deposits.

Another point that had struck him in connection with the paper was the effect of pressure and temperature in connection with the changes which were taking place. On the coast of Queensland he came across a lenticular deposit of oil shale. The sea was eroding the face of the sand dunes in places, and in the sand dunes, which were simply blown sand, loosely consolidated, of no great age, there was a deposit of this character. It was very obvious that that deposit had not suffered from very great pressure. At other places along the coast the same sort of thing occurred nearer the shore level. Neither temperature nor pressure had effected that lens very much, and yet it was a very good oil shale. It was well

consolidated, and yet it contained, when examined in detail, fragments of trees and plants which were growing on the coast at the present time in a thoroughly lignitic or jetonised condition. For instance, it contained fragments of the mangrove and Banksia enclosed in a consolidated shale. Samples of shale were taken out and distilled and yielded about 40 gallons per ton of very good oil. As a matter of fact it was quite possible that if the distillation had been done more carefully it would have yielded larger quantities of oil, but a good 40 gallons per ton could be distilled from it at the present time. The lens existed where an old water course had been choked up by the sand dunes and buried. Similar water courses were to be seen cutting through the sand dunes at present. That was one of the most interesting occurrences with regard to the formation of oil-shales in recent times that he had come across.

He thought the most interesting feature of the paper was that it indicated how necessary it was for petroleum technologists to build up their ideas with regard to the origin of petroleum. For instance, the Americans had formulated a carbon ratio hypothesis which had at present an almost entirely empirical basis. In the case of very many fields it undoubtedly worked. The atomic theory had an empirical basis and yet it held good for many years until finally it was modified when it became known that atoms were built up of very much smaller things. It seemed to him that the line of research which the author had started was the kind of research it was necessary to carry out in order to turn the carbon ratio hypothesis from an empirical theory into something which was based on actual experimental work, chemical, microscopical and so on as well as upon field work. The American idea was one which deserved a great deal of attention on the lines the author had indicated in his paper. He thought the paper was of very great value because it suggested a way in which the carbon ratio hypothesis, which was closely allied to the ideas underlying this paper, could be placed on a solid basis. He desired to deal with one other point connected with torbanitic material. The New South Wales torbanites were extremely rich. Unlike the occurrence described in Staffordshire, no genuine seepages of petroleum had been found in association with them up to the present time. He had heard many rumours of such seepages, but in no case could he verify their accuracy. At the same time that did not mean that there was no petroleum in the district, and some boring was going to be undertaken to test the beds. He drew attention to that point because no actual case of free petroleum had been found in connection with the beds except perhaps where igneous rocks had affected them.

Mr. Alexander MacDougall wished to ask the author whether he considered that in the formation of jet and of coal the differences

between those materials were due to time, temperature and pressure. The author had called jet a halfway house between wood and coal. Personally he had taken out of a boring in Ireland nearly 100 ft. deep a piece of what appeared to be wood, but it was the colour of chocolate and as hard as iron. That rather bore out what the author had said about an intermediate stage of material between wood and coal; and if he understood aright the suggestions the author made, first of all there was wood, secondly the specimen to which he had referred, which was more like bog oak and of a chocolate colour, thirdly jet which produced petroleum, and fourthly coal. He would like to know whether it was possible for the author to give an indication of the respective depths, the probable temperature and the calculated pressure in those instances. He thought Dr. Wade, who had referred to sand dunes, had overlooked the fact that the question of great ice pressure at one period had to be considered, or the material might have been carried down by the rivers from some other point. In addition, the specimen that Dr. Wade obtained might be an isolated one.

Mr. E. R. Redgrove said he thought the members would be more at home with the material if a chemical analysis had been included with the microscopical analysis, seeing that the inclusion of a chemical analysis of the materials would have helped the members to appreciate how the high yield of oil was obtained from them. He had had the pleasure of examining several of the oil seepages in North Staffordshire to which the author had referred and also one from a colliery in Derbyshire, and he found that the oil contained very little of the lighter fractions. It looked as though they had nearly all evaporated or that the oils had been formed in some peculiar manner, as the products were almost fit for use as lubricants in their native condition and they were not very far removed in chemical behaviour from the crude oil now being produced at Hardstoft.

Mr. Charles Dabell said he was sorry he could not enter into the technicalities of the subject; he would, however, like to ask the author if he had yet determined the melting point of jet. It would also be of interest if the author could state how jet ornaments were shaped.

The following was subsequently received from **Dr. P. E. Spielmann**:—

Over twenty years ago, I examined the problem of the origin of jet and attempted to connect it with the origins of petroleum and bitumen ("Chemical News," 1906, **94**, 261). Although the facts adduced were the most reliable that were available, I should not be quite comfortable, at this distance of time, if I were held strictly responsible for all the deductions that were drawn.

However, it is interesting to remember that the "cedar," as Mr. Cunningham Craig calls it, from which jet was formed, still survives as an existing tree. A specimen of jet I obtained had a line of pyrites along it, and I sent it for examination to the Natural History Museum. Mr. Aber wrote as follows:—"I think part of the Araucarian wood has been replaced by pyrites, which thus conforms to the original structure. Under the microscope one seems to see markings as of the pits of the wood elements. Such specimens are rare but not unknown."

The association of petroleum and jet is apparent by the smell that is still immediately noticeable in the old jet workings, but whether these two substances are there intimately connected, or whether the petroleum was formed from other organic remains, also enclosed in the clay, cannot yet be settled.

Two years later, Professor Constam, who was head of the Federal Fuel Testing Station, examined the fuel imported for use in industry and on the railways, as Switzerland has no coal and little lignite. Among the large number of calorific values that had been determined, there were some of specimens of jet that had been examined for scientific interest. Professor Constam was kind enough to allow me to publish them ("Chemical News," 1908, **97**, 181), and they are of present interest in supporting the clasification of jet with the cannel coals. From the determinations made and calculated for the ash-free substance, the following comparisons can be made:—

Jet	9,084 cals.
Cannel, from Ruhr	9,194 „
For comparison:	
Lignite .. .. (av.)	5,500 „
Coal (approx.)	8,400 „
Fuel Oil (approx.)	10,500 „

Mr. E. H. Cunningham Craig, in reply, said he was sorry that it had not been possible to raise any controversy in regard to his paper, because he had hoped that perhaps some bacteriologists would have been present who would have challenged some of the suggestions contained in it. The Chairman had asked a question in regard to commercial quantities of jet. So far as the production of oil went, jet did not occur in commercial quantities. It was valuable for making jet ornaments, although very little was obtained in this country now for that purpose, but a good supply was obtained from Spain which was made into fine Whitby jet ornaments. When he used the expression "in commercial quantities" he meant to convey that the yield of oil obtained would be a commercial quantity if there was enough of the jet. But the jet was only the type of mineral that he had examined in order

to get evidence about what he had called jetonised material. The specimen he exhibited of Sumatra lignite was almost perfectly jetonised and would give a very good yield indeed of oil under a modern retorting process.

With regard to the final result obtained from retorting jet, he had with him a specimen of the coke absolutely run to dryness. It was wonderfully light and feathery, and was made out of crushed jet. He also had specimens of the light oil, the water, and some of the heavy oil and the wax distilled from the jet. He had not made tests with many lignites yet, but he thought it was fairly well proved that if lignites were obtained in the proper condition, i.e., if the vegetable structures were gone or almost gone, they would certainly yield a good deal of oil. He did not say what the quality of the oil would be; that was a matter for the chemist. It was with regard to cannels that he thought the important point arose. So far as the cannel was torbanitic they had been able to understand what it would yield in oil and what kind of oil it would be, but when a cannel was largely made of jetonised material they had always been in doubt as to what the yield of oil would be and what kind of oil it would be also.

In answer to Dr. Haydon, he was sorry to say that he had never examined any of the Japanese coal to which he had referred, and he would be very glad to get some of it. He had obtained material from all over the world, but he had only selected a few specimens to work on for the paper. He did not know whether the coal to which Dr. Haydon referred was anything like the specimen of Sumatra lignite. (**Dr. Haydon** said it was very much like it). That Sumatra lignite was of Eocene age and would not have a very high calorific power under boilers, but he certainly thought it would yield 50 gallons of oil, or over, per ton in a retort.

He thought Dr. Wade's remarks showed what had been suggested in the paper, that it was possible to get woody material approaching the jet stage without any very high pressure, although the pressure was sufficient no doubt to crush the original wood into something like one-third or one-fourth of its thickness. The specimen exhibited, which was obviously a bit of a tree trunk, must have been crushed to about one-third or one-fourth of its original thickness, which showed that there had been a fair amount of pressure, but not the same amount that was obtained in coal of Carboniferous age.

With regard to what Dr. Wade said about New South Wales and torbanites, if in the domes that were described there was a sufficient thickness of strata beneath, say a couple of thousand feet, he thought it very probable that signs of oil would be found on boring. Possibly there might be enough to give production,

but it would have to be 1,000 or 2,000 ft. below the torbanitic zone.

Then some query had been raised in relation to time, temperature and pressure. The pressure, he thought, was the most important thing. Under a pressure and under a temperature which could never have been very high certain chemical changes took place in the solid wood, and those changes brought the material into a state in which it was on the way to forming a material that could be made into petroleum. He would only go so far as to say that. He did not say that hydrocarbons were actually formed, although he thought it was quite possible they were to some extent, in the jetonised material. He tried to get a specimen of bog oak to study in connexion with his investigations, but he was not able to get one about which he could obtain full particulars in time. Bog oak certainly should be a stage between wood and jet. With regard to Mr. Redgrove's point, there was no doubt whatever that in an investigation of the kind dealt with in the paper chemical analyses were required. He wished to say quite openly that he was looking for a chemist to co-operate with him in a research of that kind. There was a great deal of research to be done and he had neither the facilities nor sufficient chemical knowledge to conduct the chemical part of it himself. In reply to Mr. Dabell's question, he had not been able to melt jet in any way. It burned easily but it did not melt; it hardly intumesced at all. In making the ornaments jet was simply ground and polished.

On the motion of the Chairman, a hearty vote of thanks was accorded to Mr. Cunningham Craig.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND SECOND GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, on Tuesday evening, May 10, 1927, Mr. ALFRED C. ADAMS, President, in the chair.

The President said that before the business of the meeting commenced, he desired to refer to the very great loss that the Oil Industry and the Institution had suffered by the death of Lord Cowdray, who was a great personality in the Oil World, and a very great friend of the Institution. He was associated with the late Sir Boverton Redwood in the founding of the Institution, and was a signatory of its Memorandum of Association; he was also one of its most distinguished Vice-Presidents. The Institution was indebted to the late Lord Cowdray for a great deal of support and active help of a practical kind, and he was sure the members would treasure his memory as a man who was always ready and anxious to support in a practical way any worthy cause.

The Secretary read the following list of Members who had been elected since the last meeting:—

Members.—Frederick Gardner Clapp, August Jansen, Michael Vantu.

Transference to Member.—Arthur Philip Catherall, Cecil Evelyn Keep.

Associate Members.—Charles Thomas Child, John Chillew Daniel, Michael Edmund Hubbard, Richard Keith Van Sickle.

Transference to Associate Member.—Joseph Coates, Ernest Douglas Irving.

Students.—Douglas Henry Carter, Robert Alexander Fraser, Harry Cecil Rampton.

Associate.—Owen Reginald Kirby.

Transference to Associate.—Alfred James Foster.

The President said the members were to have the opportunity of listening on the present occasion to a paper by Messrs. Kewley and Jackson on the subject of "The Burning of Mineral Oils in Wick-Fed Lamps." He was quite sure that, after the members

had heard the paper and the description of the exhibits, they would be of the opinion that the authors had dealt with a subject of very great practical interest.

The following paper was then read :—

The Burning of Mineral Oils in Wick-Fed Lamps.

By J. KEWLEY, M.A., F.I.C., and J. S. JACKSON, B.Sc., A.I.C. (Members).

THE development of methods of artificial lighting is by no means the least of the achievements of the nineteenth century. It is hard to realise that prior to a time within the memory of living men the only methods of illumination available were little in advance of those employed in the days of the Greek and Roman empires. The earliest known means of providing artificial light was probably the torch. This must have been superseded at a very early date by some form of primitive lamp, as according to mythological legends Apulcius makes Psyche drop hot oil from a lamp on Cupid. As early as the first century B.C. rushlight candles had come into use. There is a fragment of such a candle in the British Museum. About 1775 the sperm whale fishery came into being, in 1786 386 tons of sperm oil were imported into England, and sperm wax candles came into use. Somewhat later three important factors contributed to a considerable development in the art of lighting. These were :—

1. The invention of the Argand lamp in 1784 ;
2. The initiation of the coal gas industry in the early days of the nineteenth century by Murdoch and Winser ; and
3. The birth of the petroleum industry nearly half a century later.

The rate at which these industries developed is an index of the magnitude of the latent demand for better illumination in those days. To the satisfaction of that demand the petroleum industry devoted itself for many years, kerosine being the centre of gravity of the industry. This has now completely changed, and kerosine no longer plays the leading part. Nevertheless, the quantities used for illuminating purposes are still so great that the subject has by no means lost its importance.

A few words on the development of the kerosine lamp and on the liquid illuminants first used may not be out of place as an introduction to the subject.

The first invention of importance was undoubtedly that of Ami Argand, who in 1782 devised a lamp in which arrangements

were made for regulating and directing the supply of air, thus making possible a clear, steady, smokeless flame. In his patent he claims "to give neither smoak nor smell, and to give considerably more light than any lamp hitherto known." His first lamp had an iron chimney suspended over the flame, but this was soon replaced by one of glass. The wick was tubular, the necessary air being supplied through the centre tube as well as outside through the perforated metal platform on which the chimney stood.

FIG. 1.

PRINCIPLE OF ARGAND BURNER.
Arrows show direction of air currents.

The oil was supplied to the wick by means of a tube, the reservoir being above the wick. The plain cylindrical chimney of Argand was modified to a tapered form by Smethurst, the lower part of the chimney being widened out to a bulb. A great advance was made when a flat wick was forced to adjust itself to an annular tube, as in present-day lamps. The burner was also modified by the introduction of a plate, the so-called "Liverpool button," above the wick, the function of which was to direct the air coming up the central tube against the inner wall of the flame in order to improve the combustion.

In 1852 Stobwasser designed an Argand burner for use with coal oil. J. H. Austen introduced into the United States the Vienna burner, and Young produced the first English mineral oil lamp for shale oil. This lamp, known as the "oxydate lamp," had a flat metallic tube within which the wick was raised and lowered by a simple lever, the air was supplied by means of an elliptical deflector or cone, and a glass chimney was fitted. In 1865 Hinks introduced the well-known Duplex burner. Develop-

ment then went apace, and a host of lamps of great variety appeared on the scene.

The illuminants in use before the advent of kerosine were vegetable and similar oils and the so-called "camphine," a mixture of alcohol and oil of turpentine.

About the middle of the nineteenth century manufacturers began to turn their attention to the production of mineral oils. In 1840 a "coal oil" was produced in France by the distillation of bituminous coals. Similar oils were made in America. The Kerosene Oil Company of New York began operations in 1854, working, under Gessner's patents, on the Albertite of Nova Scotia. Within twenty years fifty or more coal oil refineries had sprung up in the United States. In 1847 Playfair found an oil in the Atherstone Colliery. Young distilled and refined this oil and later initiated the famous Scottish shale oil industry. In 1855 Professor Silliman, of Yale, who had done some work on "rock oil," predicted that from that crude material "as good an illuminant as any the world knew might be made."

In 1857 the Carbon Oil Co. received their first consignment of twelve barrels of crude petroleum from Tarentum, Pa., and worked it up into kerosine. This was the beginning of the history of petroleum as an illuminant.

The old type of wick-fed lamp, because of its cheapness and simplicity, is still by far the most widely used, but several types of incandescent mantle lamps in which the kerosine is vapourised and mixed with air before combustion, and which are much more efficient, are coming more and more into use, particularly for special purposes. In this paper, however, the burning of kerosine in lamps of the wick-fed luminous flame type only will be considered. This is a subject apparently simple, but actually difficult, about which little has been published. The authors feel that although they have by no means adequately dealt with the subject, the data and considerations herewith put forward are of sufficient interest to deserve attention and perhaps to stimulate discussion and further work.

The behaviour of the flame when the lamp is first lit depends mostly on the chemical character of the kerosine, considered, of course, in relation to the type and construction of the lamp used; and its subsequent behaviour depends largely on its physical properties again in relation to the construction of the lamp.

The problem of devising for the examination of any product laboratory tests which have some definite relation to the behaviour of the product in actual use is often one of great difficulty. Too often tests are carried out (even laid down in specifications) which are not only useless, but worse still, sometimes misleading, as an

indication of the way in which a product will behave under service conditions.

In order to tackle this problem it is necessary in the first place to be quite clear as to the requirements to which a good illuminating kerosine must conform. Apart from the æsthetic considerations of colour and odour, a good illuminating oil :—

(*a*) must have a good initial illuminating value ;

(*b*) must have the power of retaining this good value as the oil is consumed ; and

(*c*) must not cause deposits of any kind on the lamp chimney.

All essential features will be found to fall under these three heads. If an oil fulfils these three conditions it will be a satisfactory illuminant in any ordinary wick-fed luminous flame lamp of the types in general use. The primary problem is, therefore, that of finding out what characters or properties of the kerosine are related to these requirements, and the secondary one is that of designing laboratory tests which will give reliable measures of these characters.

To assist in the consideration of these points in detail a number of analyses of present day kerosines of various types are given herewith for reference.

It will be noticed that these kerosines show great diversity of composition and character. Leaving out of consideration for the moment impurities, it will be noticed that for similar boiling point ranges there are wide variations in the specific gravity. This is, of course, due to the variation in the nature of the component hydrocarbons. These kerosines show also great differences in respect to burning quality. This property must naturally be considered in relation to the actual type of lamp used. It is proposed, therefore, to consider kerosines in relation to the types of wick-fed household lamp in general use at the present time. As the problem is distinctly involved much work has been done, a great deal of which was negative in character, but much of which has given results of definite value.

The burning quality of any kerosine will obviously depend on three main factors : (*a*) its chemical composition, (*b*) its physical properties, both considered in relation to the construction of the lamp, and (*c*) the impurities present.

It will be as well to take the last first as being simplest.

A good kerosine should presumably consist entirely of hydrocarbons. The only impurities likely to be found in a kerosine are sulphur compounds, oil soluble naphthenates, or sulphonates. Naphthenates or sulphonates of sodium would presumably be undesirable impurities, as being non-volatile they would tend to

TABLE 1.

TYPES OF COMMERCIAL KEROSINES.

Sp. gr. at 15/4° C. ..	0·790	0·794	0·796	0·802	0·804	0·808	0·809	0·811	0·821	0·822	0·826	0·826	0·835	0·850	0·851
Distillation A.S.T.M.															
Initial boiling pt. °C.	156	149	155	187	148	165	143	133	140	138	150	190	145	153	154
25% vol. .. „	198	175	185	216	175	206	193	182	177	178	188	203	176	192	186
50% „ .. „	226	195	197	235	194	223	216	208	204	211	217	217	193	211	205
75% „ .. „	257	222	214	260	218	241	240	238	236	248	248	230	215	234	224
Final boiling point „	314	286	261	328	276	292	304	300	305	300	298	277	270	285	267
% to 200° C.	28	56	57	7	57	15	31	43	47	42	35	20	59	35	43
Sulphur, % wt.	0·02	0·12	0·16	0·02	0·13	0·09	0·08	0·12	0·04	0·05	0·04	0·16	0·40	0·04	0·04
Aromatics, % wt. ..	10	17	16	11	17	18	15	14	26	14	23	19	26	40	23

augment carbonisation of the wick. Attempts were made to determine the ash of various kerosines, but the quantities found were so minute as to be outside the range of a practical method. The sulphur compound impurities, however, play an important part in that they are largely responsible for the formation of bloom in the chimney, the white bloom as distinct from a dirty bloom caused by smoke.

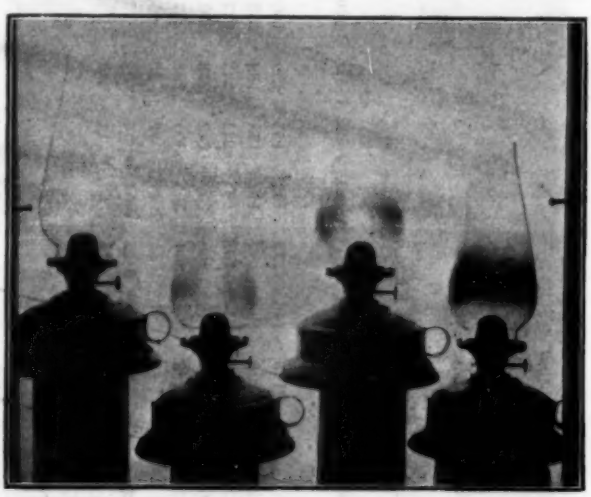

FIG. 2.

EFFECT OF S. CONTENT ON BLOOM.
(Sulphur contents 0·05, 0·15, 0·25, 0·50.)

The formation of this white bloom depends not only on the presence of sulphur compounds in the oil but also on the presence of impurities in the atmosphere. The same kerosine, burnt under the same conditions as regards lamp, but under various atmospheric conditions, will display varying amounts of bloom. The incidence of a smoke fog particularly increases the bloom formation. The presence of ammonia in the atmosphere in which the oil is burning also induces the formation of bloom. The presence of ammonium salts in the bloom may easily be detected by dissolving it off and testing in the usual way.

This points to the importance of a pure atmosphere for the carrying out of burning tests, or else the making of a blank or

comparative test with a kerosine of known properties simultaneously. Another factor which affects bloom formation is that of the alkali in the glass of the chimney. Bloom is always more marked when using a new lamp glass and such bloom contains sodium sulphate.

FIG. 3.

EFFECT OF USE ON BLOOM OF LAMP CHIMNEYS.

After a lamp chimney has been used and washed several times the influence of this factor disappears. There are thus two obvious pitfalls to be avoided if bloom formation is to be accurately estimated.

However, in an ammonia-free atmosphere using an old and often washed lamp glass, bloom still forms in certain types of lamp if the kerosine contains a relatively high percentage of sulphur. Such bloom appears to consist largely of organic sulphonic acids or bodies of similar nature, but it contains also inorganic constituents. In order to eliminate the effect of the glass a chimney of silica was obtained. A brownish bloom on this chimney, which on extraction with benzol yielded some heavy oily matter, was

dissolved off in dilute nitric acid. It was found to contain sulphates of ammonium and sodium with traces of potassium and calcium. It is considered that these latter may be derived from the wick, the ash of which contains these constituents.

Moreover, any bloom formation depends to a large extent on the design of the lamp chimney, as deposits form more readily on a relatively cool surface. Thus a Kosmos lamp glass will show less bloom than one of a bulging type with the same kerosine under the same conditions.

It is evidently inadvisable to specify any maximum percentage of sulphur for a kerosine, unless the conditions under which it is to be burnt are known. The small percentages of sulphur found in kerosines have no influence on the illuminating value, apart from the indirect one of bloom formation.

The influence of the chemical composition on the burning quality is a much more difficult question. The first difficulty is to decide exactly what is meant by burning quality or illuminating value. It may be taken that, other things being equal, the larger and brighter the flame obtained initially or a short time after lighting the lamp, the better the kerosine. As a matter of fact brightness and size of flame go hand in hand. Those kerosines which give reddish flames tend to smoke more readily, and so cannot give a large flame. The initial candle power is thus a direct measure of the illuminating value. The determination of this initial candle power is, however, by no means an easy matter. In the first place a standard lamp must be used. As the earliest kerosines to come into general use were those of the paraffin type, such as those made from Pennsylvanian crude, the lamps first made were designed to burn such oils. Kerosines from other types of crudes, particularly those rich in aromatics, will only burn in such lamps with reddish flames and a marked tendency to smoke.

This is, however, quite as much the fault of the lamp as of the kerosine, as lamps can be designed to burn kerosine of very high aromatic content perfectly well. As an illustration of the effect of the design of lamp the following data may be considered :—

A Mexican kerosine with a Hinks duplex lamp gave an initial candle power of 33·6, an East Indian kerosine in the same lamp only 26·8, the Mexican thus showing a superiority amounting to 25 per cent. ; with a Mikado lamp the initial candle powers were 22·4 and 20·2 respectively, the superiority of the Mexican in this case being only 11 per cent.

It is of course well known that in many types of stoves the air supply is so great that a kerosine of the paraffin crude type burns with an almost non-luminous flame.

In order to investigate the effect of the chemical composition of the kerosine on its illuminating value, all other factors as far as possible must be kept constant (such as boiling range, capillarity, viscosity, etc.). The difficulty of trimming a lamp wick so that repeatable initial candle powers can be obtained is so great that the ordinary method of photometric observation of the initial candle power is impracticable. Apart from this difficulty some standard height of flame is desirable if the character of the oil is to be judged by the candle power. Adjustment of the flame to a standard height by means of a gauge as recommended by the A.S.T.M. or by means of one attached to the lamp has been tried, with but slight success. Investigations on determining candle power were therefore discontinued owing to wick trimming difficulties.

The initial candle power of a lamp flame is really determined by the tendency of the flame to smoke. The poorer the illuminating value the lower the critical height of the flame at which smoking takes place and vice versa. The better the kerosine, the larger the flame and the lower the susceptibility to draught. Attention was therefore turned to the problem of devising some test, simple, rapid and reliable, for measuring the "tendency to smoke." The first attempts made were in the direction of measuring the susceptibility to draught, and met with little success. There must be for every kerosine in any given lamp a critical height of flame, beyond which it will commence to smoke. At these critical heights the susceptibilities to draught must be so great that relative differences cannot well be observed. Attempts were therefore made to determine the relative susceptibilities to draught of flames of standard heights. For this purpose a rotating table was used, the lamp being fixed in a clamp near the circumference, and the table rotated by an electric motor. The number of revolutions per minute when the flame began to smoke was taken as the susceptibility to draught. In this way results of some value were obtained. Good kerosines were able to stand about thirty revolutions per minute, bad ones only ten. The difficulty of trimming the wick to a perfect flame was still present, so the method was discontinued as unsatisfactory. Similar experiments in a wind tunnel were discontinued for the same reason.

The staff of the laboratory of the Bataafsche Petroleum Mij. at Amsterdam, who were also occupied with the same problem, tackled it from the point of view of determining the maximum size of flame which a kerosine could give under certain conditions, when just on the point of beginning to smoke. For this purpose a very convenient apparatus was found ready to hand in the benzine lamp supplied with the Weber photometer. This small lamp will perhaps not be generally known where Weber photometers are not

in use. It consists of a cylindrical container 130 mm. x 20 mm. with a central circular wick, 4½ mm. diameter, which can be adjusted. The trimming of such a small wick is an easy matter, as the flame is conical. The housing of the lamp carries a millimeter scale on

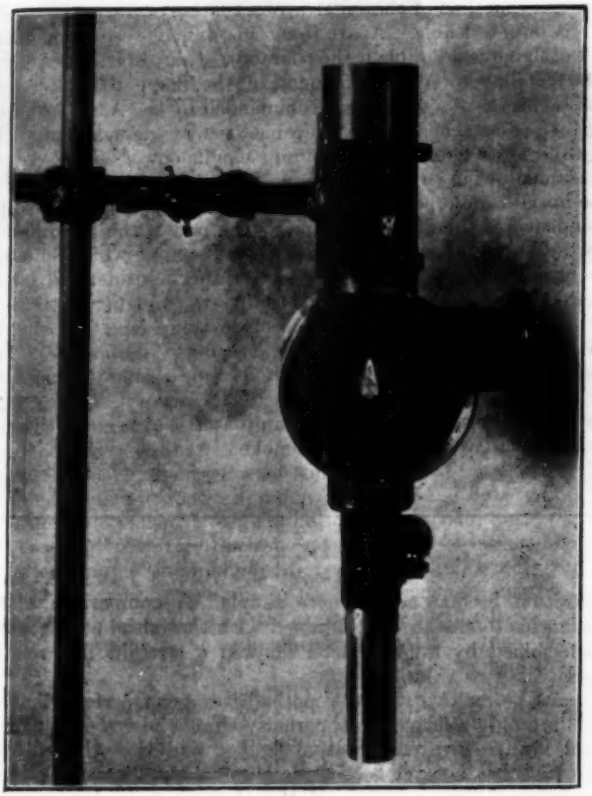

FIG. 4.

the window and a mirror behind the flame, so that the height of the flame can be easily and accurately read. The flame at the critical height is very sensitive, the slightest increase in height causing the development of a long smoky tail.

With the help of this apparatus a classification of kerosines according to their "tendency to smoke" becomes a relatively easy matter, so that investigations into the effect of chemical

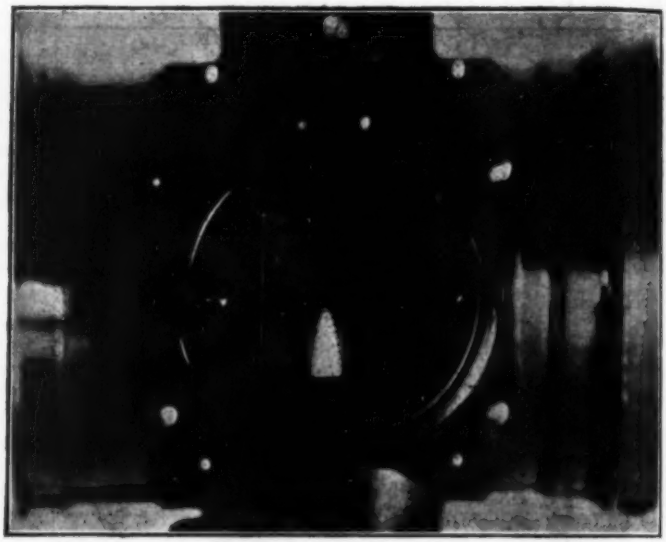

FIG. 5.

composition become much more simple. A comparison of the "tendencies to smoke" so obtained with the initial candle power as determined by a photometer showed a straight line relation between the two values.

It must be realised that the method is not yet perfect, that the figures are only relative, as apparently similar pieces of apparatus do not always give comparative figures, and that the influence of the wick has not yet been quite eliminated. Nevertheless, the apparatus is of distinct value. With its help the following investigations have been carried out:—

1. The relative values of paraffins, aromatics and naphthenes.

Owing to the difficulty of obtaining kerosines of the necessary boiling range, of which the chemical constitution is definitely known, an Edeleanu Extract has been taken as typically aromatic, a kerosine of low specific gravity heavily treated with oleum as

paraffin, and a kerosine generally considered naphthenic, as naphthenic.

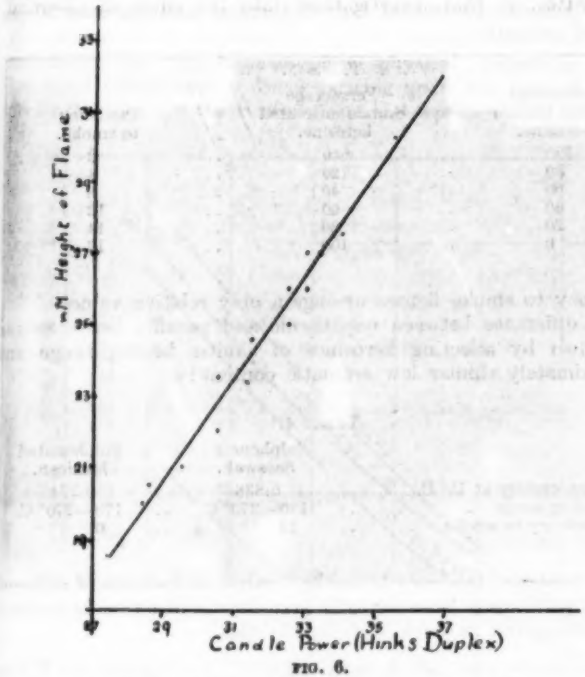

FIG. 6.

DIAGRAM SHOWING RELATION OF "TENDENCY TO SMOKE" TO INITIAL CANDLE POWER.

The influence of aromatics is well shown by the data given in Table 2. As "paraffins," a kerosine made by heavily treating a light Mexican oil with oleum was used, and as "aromatics" an Edeleanu Extract from Borneo kerosine :—

TABLE 2.

Percentage paraffin component.		Percentage aromatic component.		Tendency to smoke.
100	..	0	..	0
95	..	5	..	3
90	..	10	..	6
85	..	15	..	10
80	..	20	..	12
70	..	30	..	18
60	..	40	..	22

Table 3 shows a similar set of data obtained on mixtures of Borneo kerosine after heavy oleum treatment with untreated Borneo kerosine (untreated Borneo kerosine contains over 30 per cent. of aromatics) :—

TABLE 3.

Percentage treated Borneo kerosine.	Percentage Borneo untreated kerosine.	Tendency to smoke.
100	0	2
80	20	4
60	40	8
40	60	12
20	80	14
0	100	17

Tendency to smoke figures are again only relative values.

The difference between naphthenic and paraffin kerosines can be shown by selecting kerosines of similar boiling range and approximately similar low aromatic content :—

TABLE 4.

	Sulphonated Sarawak.	Sulphonated Mexican.
Spec. gravity at 15° C.	0·838	0·774
Boiling range	170—270° C.	170—270° C.
Tendency to smoke	12	0

The relative " tendency to smoke " values of fractions of different boiling point range from the same kerosine can also thus be studied. The data given in Table 5 exemplify this :—

TABLE 5.

Fraction.	Boiling point range.	Tendency to smoke.	Sp. gr.	% wt. aromatics
1. 27% vol.	155—173	3	0·783	15·3
2. 24% vol.	173—185	5	0·795	16·9
3. 24% vol.	185—200	6	0 802	17·4
Residue 24% vol.	200—262	14	0·820	18·5

The initial illuminating power of a kerosine is thus mainly determined by its chemical composition; in the case of kerosines of similar boiling point range entirely so.

A high initial candle power is, however, not the only desideratum. The maintenance of the candle power as the oil is consumed is a point of great importance. This depends to a considerable extent on the second of the three factors mentioned above—viz., the physical properties of the oil. It can be said in a general way

that the maintenance of a satisfactory flame merely resolves itself into a problem of maintaining a sufficient supply of oil. Unfortunately, this is affected by many factors entirely outside the properties of the kerosine itself. Leaving these out of consideration for the moment, the physical properties of the kerosines which have a direct bearing upon the rate of feed of oil to the wick are the viscosity and the capillarity:—

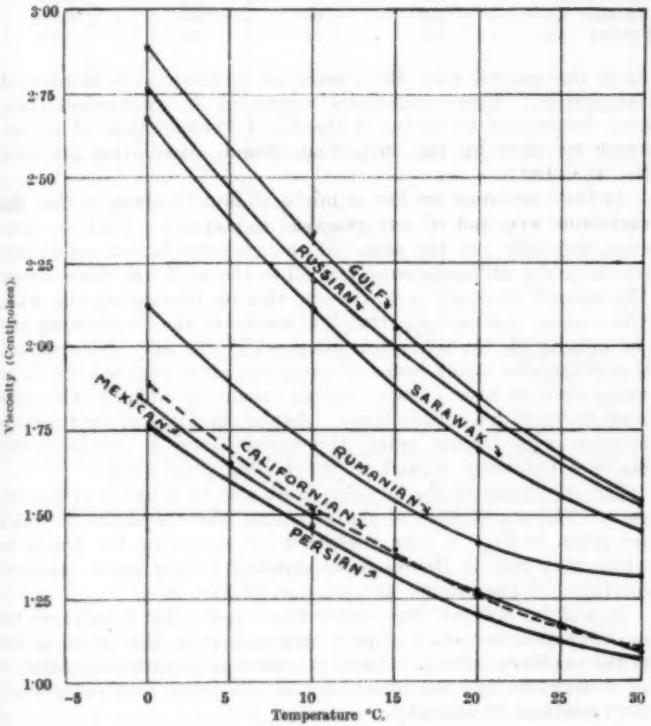

FIG. 7.

VISCOSITY CURVES FOR VARIOUS KEROSINES.

The viscosities of a number of kerosines from various sources have been determined and found to show differences for kerosines of approximately similar boiling ranges. The boiling point ranges

of the kerosines, the viscosities of which are shown in Fig. 7, are as follows :—

TABLE 6.

Type.	I.B.P.	% to 200.	F.B.P.	Sp. gr. 15° C.
Gulf	154 ..	29 ..	309 ..	0·812
Russian	137 ..	40 ..	316 ..	0·823
Sarawak	154 ..	45 ..	265 ..	0·848
Rumanian ..	135 ..	54 ..	312 ..	0·822
Californian ..	149 ..	61 ..	272 ..	0·800
Mexican	156 ..	60 ..	262 ..	0·796
Persian	143 ..	61 ..	290 ..	0·791

As is the general rule, the viscosities decrease with increase of temperature. These viscosities expressed in centipoises have been determined by means of the No. 1 Ostwald type of viscosimeter specified by the Brit. Eng. Stand. Association (Bulletin No. 188, 1923).

As the viscosities are low it might at first be thought that the variations were not of any practical importance. Such is, however, definitely not the case. If the viscosity is not sufficiently low to ensure an ample supply of oil to the wick, the flame drops. The natural tendency is to remedy this by turning up the wick. This causes a temporary rise, but results in the overheating and carbonising of the over-protruding wick. It may be expected that a kerosine which burns in any given lamp with a large flame would need to have a lower viscosity than one which in the same lamp burns with a smaller flame. As the viscosities of the fractions increase with boiling point the maintenance of candle power becomes indirectly related to the boiling point range.

The capillarity of the kerosine must also be a factor of importance. The capillarities of the kerosines (the viscosities of which are given in Fig. 7) were compared by measuring the height to which they rose in thermometer capillary tubing under standard conditions. The results are set out in Fig. 8.

It will be noticed that under these particular conditions the most viscous kerosines showed approximately the greatest rise in the capillary tubing. This observation is of particular interest, as it suggests that the capillarity of a kerosine may compensate for variations in viscosity.

A factor which has a great influence on the falling off in candle power as the oil is consumed is the extent to which the wick carbonises. The authors have not yet completed their investigations into this problem, but from the evidence so far obtained it appears to them that this effect is distinctly related to the viscosity and chemical composition of the oil. Should the viscosity of an oil be unduly high, then the amount of oil supplied

to the wick as burning proceeds may be insufficient for the surface of the wick exposed, so that portions of the wick project into the hotter regions of the flame and thus become carbonised. Once this starts the effect becomes cumulative.

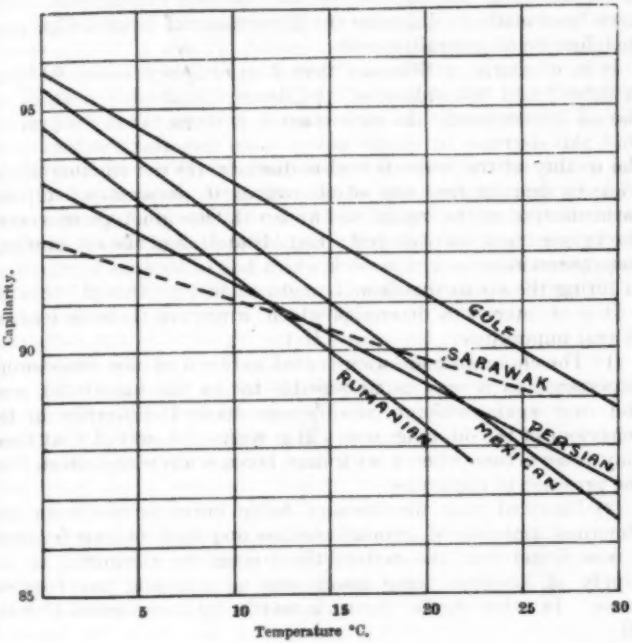

FIG. 8.

KEROSINE (CAPILLARITY).

There is evidence that the chemical composition of the oil influences the extent of the carbonisation of the wick. Oils of high aromatic content are definitely offenders in this respect. A distinction must be made between the loose carbonaceous crust found on the top of the wick and the mere darkening or charring of the wick material. The extent to which the wick is charred is really only an indication of the extent to which the wick has been turned up, so that, paradoxical as it may seem, the greater the charred area the higher the initial candle power of the kerosine.

Although the essential properties of a satisfactory kerosine for use in any reasonable lamp can now be specified, an ideal kerosine

may nevertheless be found to give poor results in some of the extraordinary lamps occasionally offered for sale, the design of which is apparently sometimes determined by æsthetic and commercial considerations with little regard to the conditions under which the oil must be burned. Several experiments which have been made to illustrate the importance of lamp design may therefore be of general interest.

It is, of course, well known that if an ordinary household lamp is lighted and left untouched the flame will steadily decrease as the oil is consumed. In such cases it is often taken for granted that this decrease in candle power is an important indication of the quality of the kerosine and is due to: (1) the choking of the wick by heavier fractions of the oil or by impurities; (2) the carbonisation of the top of the wick; (3) the gradual removal of the lighter fractions of the oil; and (4) the fall of the oil level and consequent increase in the work which has to be done by the wick in lifting the oil to the flame.

It is of interest to determine which, if any, of these factors are of real importance.

(1) The choking of the wick is obviously not of any considerable importance, as it was found possible to use the same wick over and over again without causing any marked difference in the behaviour of the oil under test. It is realised, however, that there may come a time when a wick does become adversely affected by the presence of impurities.

(2) Provided that the kerosine being burnt is free from any abnormal amounts of aromatic bodies and high boiling fractions it was found that the carbonisation could be attributed to the supply of kerosine being insufficient to maintain the required flame. In other words, the wick was being burnt instead of the oil.

(3) The possibility of any change in the composition of the kerosine taking place during a burning test was effectively disposed of by carrying out distillation tests before, during and after a prolonged burning test. The distillation figures obtained showed no variation at all, thus establishing conclusively that fractional removal of the more volatile constituents does not take place during a prolonged period of burning. This point was cleared up as long ago as 1883 by Nakamura (J.S.C.I., 1883, page 535).

The fall in the oil level was, however, shown to have by far the greatest effect upon the behaviour of the oil. This was demonstrated in various ways. In the first place a constant level device was attached to a standard testing lamp. When working under the ordinary standard conditions it was found that the usual drop in candle power did not take place, in fact that a uniform

candle power was maintained throughout the test. As a matter of interest the test was continued for 72 hours without any appreciable fall in candle power.

This led to the production of a lamp with a very shallow flat reservoir. With this shallow reservoir it was found that with any well-refined kerosine which would give a satisfactory initial candle power, a steady flame could be maintained throughout the test without any drop in candle power taking place.

On the other hand lamps may be purchased which will not burn even the very best kerosines unless the reservoir is more than quarter full.

The reason for this is that the oil level when the reservoir is quarter full is nearly ten inches below the flame, so that whatever the viscosity and capillarity of the oil may be, the wick is unable to supply sufficient oil to maintain the flame.

The important effect of the oil level upon the candle power obtained is strikingly demonstrated by the figures in Table 7.

TABLE 7.

Time.	Candle Power. Shallow Reservoir.	Deep Reservoir.
0	20·0	20·0
20 mins.	20·0	14·6
1 hr.	20·6	13·8
1½ hrs.	21·5	13·4
2 „	21·8	12·8
4 „	21·8	12·0
6 „	21·8	11·6
8 „	21·8	11·0
10 „	21·8	10·2
12 „	21·8	10·2
14 „	21·8	4·2
15 „	Oil consumed	2·6

These figures represent the candle powers obtained with the same kerosine, wicks, burners and glasses, the only difference being that a flat reservoir was used in one case and a deep one in the other. This effect was indeed noticed and described by Thœrner in 1886 (*vide* J.S.C.I., 1886, page 373), and a constant level lamp was patented by Witting of Osnabruck about that time.

The foregoing observations lead the authors to the conclusion that the initial candle power of a kerosine depends mainly on its chemical characters, and that its subsequent behaviour depends not only on its chemical characters and impurities but also to a very large extent indeed on its physical properties; that the design of the burner and chimney have a great effect on the initial candle power obtainable and the reservoir also on the

behaviour of the oil as burning proceeds. It is felt that much still remains to be done before our knowledge of this subject can be regarded as in any way complete.

The authors in conclusion wish to express their thanks to the members of the staffs of the laboratories of Shell-Mex, Ltd., and the Bataafsche Petroleum Mij., who have carried out the experimental work, to their directors for permission to publish these results, and to Mr. McLellan, of Messrs. Falk Stadelmann & Co., for kindly lending us lamps for experimental purposes. Those who are interested in the early history of the subject may find further details in :—

Practical Treatise on Coal, Petroleum and other distilled oils. Gesner, Balliere Bros., N.Y., 1865.

Solid and Liquid Illuminants. L. Field. J. Roy. Soc. Arts, 1883.

Petroleum and its Products. Redwood. J. Roy. Soc. Arts, 1886.

The Petroleum Lamp. Thomson and Redwood. C. Griffin & Co., 1902.

DISCUSSION.

The President said they had listened to a very interesting paper on an extraordinarily difficult subject. Personally, he could only approach it from the point of view of an ordinary user of kerosine wick-fed lamps. He had hoped the authors would have thrown some light upon the difficulties with which the ordinary member of the public was confronted when using such lamps, but it seemed to him, after hearing the paper, that provided a lamp, properly designed, constructed of good material, and with a really efficient wick was obtained, the only remaining difficulty was to find proper kerosine to burn in the lamp. The difficulty of the ordinary user was to find that proper kerosine, and how to identify it when he had got it. Personally, he had never been able to discover any way by means of which certainty of that result could be arrived at.

Dr. W. R. Ormandy thought that many of the members might not be as interested in the question of the relationship of oil to a lamp as the very big community in the country undoubtedly were. He thought it was an extraordinarily interesting thing that the Shell Company, in the person of its investigators, seemed to be able to apply science and scientific methods of investigation to problems of real practical every-day importance. He desired to remind the members of the wonderful work that was done by

Ricardo, in conjunction with the Shell Company, on the question of the behaviour of various types of petrol, aromatics, and so on, in the internal-combustion engine; and the present paper was a practical example of the utilisation of scientific methods in a scientific problem as applied to every-day life. The point raised by the authors with reference to the influence of sulphur was most interesting in that it was borne out in another realm of industry, which was far removed from that of illumination, and it was probably of interest just to refer to it.

Bent plate glass for windows is formed by heating flat sheets of plate glass to a temperature which softens them so that they bend round special formers. The temperature required for this purpose is not very high, but it has proved very necessary to use a gas for heating the furnace which shall be free from sulphur, otherwise the polished surface of the glass gets a bloom which reduces the value very considerably.

Another aspect of the paper which had interested him very much was the remarks made in relation to capilarity and viscosity, two factors which appeared to vary not necessarily in the same direction. He thought the study of capilarity in its relation to viscosity might be of some interest in its bearing on the constitution of oils. That was one of the greatest difficulties with which all experimenters were faced at the present time in their efforts to correlate physical properties and chemical properties of oil, the fact being that no method had as yet been discovered for determining the constitution of the oils. Anything physical or chemical which might help in that direction would be of the greatest help in making for necessary progress. Possibly the discovery that inorganic salts which might be present in the wick and in exceedingly small traces in the oil played a rôle in the question of bloom might have some bearing on the idea that the wicks of kerosine lamps should before use be soaked overnight in ordinary household vinegar. It might prove to be the case that the inorganic constituents which partly led to the formation of bloom might to a certain extent be removed by soaking in an acid solution. The various points raised by the authors were of the very greatest value. For instance, it was certainly of great importance that it should be possible to determine the value of an oil for lamp purposes, merely by determining three factors, the whole of which could be done in one hour instead of by photometric determinations, which, in view of the varying colours of the light, were exceedingly difficult to make. As far as he could understand the problem at the present moment it was as follows. The authors had referred, among others, to oils containing a high concentration of aromatic hydrocarbon, but they

had been very careful to define aromatic hydrocarbons as bodies removable by means of oleum. He gathered, therefore, that the more the authors knew about the constitution of oils, the less were they inclined to make the specific statement that these were aromatic hydrocarbons. The authors stated that such products, known as aromatic rich oils, could be efficiently burned in a lamp of a suitable character, and that the earlier paraffin rich products obtained from Pennsylvanian oils did burn satisfactorily in lamps that were developed for burning that type of oil. But the user was in the unfortunate position of not knowing whether the best class of lamp he could buy for a specific purpose would be suitable to the best sort of oil he could buy, which might not be intended for use in that lamp.

Mr. N. A. Anfilogoff said that when he saw the array of lamps on the table he could not help recollecting 1896 to 1898, when he spent days and nights in measuring flames and taking photometric records of flames and of the number of c.c.'s used by a particular lamp compared with others. The lamps were old familiar friends, and he was grateful to the authors for bringing them back to his recollection. Further, he desired to say that he thought the paper was either twenty-five years too late or thirty years too soon. In days gone by, when the trade had no use for what was called petrol at the present time, there were two grades of kerosine. Naturally, the central portion, the portion which had the closest boiling-points, was kept as Class A kerosine, being called " water white " and certain other names and sold at a higher price, and was, of course, the best lamp oil. The tails of the distillation and the heads of the fraction, which included as much as the manufacturer dare put in of petrol so that the flash-point did not fall below 73°, was used as the second-grade kerosine. This was the export quality from U.S.A. which we had. Dr. Ormandy had expressed his pleasure at the fact that the Shell Mex laboratories were now thoroughly investigating the subject, but he desired to suggest, for the sake of those engaged in the industry in the old days, that they did not work quite so much by rule-of-thumb methods as appeared to be the case, because the heads and tails of the distillation had to be blended in such proportions in the kerosine that the viscosity or the capilarity of the oil enabled it to burn without going out. That fact was brought home to his mind when he saw the photographs of the smoky chimneys. In the days when he had to make kerosine to compete against all comers on the market, the oils were tested one against the other in identically the same lamps. That was in the old days when sulphur-containing oils perhaps did not exist, but certainly smoky ones did. He remembered a

certain company in the East Indies which was concerned with some oils which were very difficult to refine. The late Sir Boverton Redwood had a barrel of the oil brought over to this country, and he (Mr. Anfilogoff) carried out some research work on it. While he was doing so, a colleague of his, who had been sent out to the refinery with the object of trying to make the oil burn, after struggling with it for some time, cut the Gordian knot by making a journey to Austria, where he and some lamp-makers between them designed a lamp, many hundreds of thousands of which were afterwards distributed gratis and for nothing throughout India, and the oil itself sold rapidly. That brought him to the point he wished to make, namely, that it did not matter how difficult an oil might be to deal with, everything depended upon the construction of the burner and the lamp as to whether it would give good, bad or indifferent results. With regard to the remarks made by the President, it must be borne in mind that in a village where oil was used for lighting purposes the villager simply went to the nearest oilshop and was sold a lamp without knowing whether it would work with the particular oil that was sold at the same time. Assuming that the purchaser was fortunate, and that both the oil and the lamp happened to fit, everything worked all right. In the course of time the wick burned out and it was necessary to go to the same oilshop to buy a piece of new wick, and that was where the trouble occurred. There were probably no two pieces of wick in the shop which were alike. In the first place, there was a wick which was very loosely woven, which helped to draw the oil up; on the other hand, there was a very tightly woven wick which, if the viscosity or the capilarity of the oil was not of the highest quality, would give bad results. Or it might so happen that the wick was damp. He did not know what happened to the wick which Dr. Ormandy stated was soaked in vinegar; but if a wick was damp, once the oil got into the wick it would never get dry. No company which was supplying oil could be expected to safeguard the consumer against all the various concomitants which entered into the question of making a lamp burn well, indifferently or badly. In fact, in the old days one importing company actually subsidised the wick manufacturers. He did not know how many lighthouses there were in the kingdom, but certainly some of them were still using oil. One particular lighthouse, until it was put out of commission comparatively recently, had consistently, during the past thirty years, burned Scottish shale oil with a gravity of something like 0·835 and 0·840 and a flash-point of 160° F. If anybody were to look at that oil casually and without smelling it, he would say it was a refined gas oil. Nevertheless, the Trinity Brethren would not use any

other and consistently used that heavy shale oil, which gave the best results. The construction of the particular lamp might have something to do with the question, but he also knew that the oil was used with a peculiarly loosely-woven wick; it could not be used with a tightly-woven wick. Quite recently he had read about the various oil policies that existed in regard to the United States; he had heard of various conferences which were going to be held in Canada; in fact, since the Institution had been formed, he had heard the statement made in the room in which the present meeting was being held that it was daily expected the oil supply of the world would fail, and that in time to come history would repeat itself and the inhabitants of the world would be forced to use oils which more nearly approximated to the shale oil used by the Trinity Brethren in their lighthouse lamps. If that happened to be the case, it might help the chemists thirty years hence to have the authors' paper before them, as it would show them all the troubles they had to look for.

Mr. Sidney T. Minchin said it so happened that the work recorded by the authors ran practically parallel to the work on which he had been engaged. In practically every major conclusion the work was in agreement, but there were several minor differences and possible additions which he proposed to discuss. These, however, would not be dealt with in any great detail, since he hoped to publish a record of them in due course. The first point was in connection with flame brightness. He agreed generally with the authors that the larger and brighter the flame the better the kerosine. But he was not at all clear what the authors meant by "brightness." Did they mean the whiter the flame, or the more intense the flame? He had found that the higher the aromatic content, certainly the redder the flame, but the more intense the light given per square cm. of radiating surface.

With regard to trimming, practically all the experiments the speaker had performed were made with the Saybolt lamp, and that, of course, necessitated trimming the wick. The method used was not the A.S.T.M. method, but the flame was turned up to the highest point short of smoking, the candle power then being taken. Trimming was admittedly difficult, but was it so serious as the authors would appear to suggest? The results obtained by the use of the Saybolt lamp by that method confirmed, and to a certain degree extended, the results given in the paper, so that he concluded that the Saybolt lamp was at least equal in utility to the apparatus described by the authors for that type of work. He agreed with the authors that tendency to smoke was a function of the highest obtainable initial candle power, but was inclined to lay stress on the flame area rather than the

flame height for ordinary lamps. As the wick was turned up, so, not only did the flame height increase, but the flame area. Since candle power was dependent on flame size, the flame area was the important factor.

With regard to the effect of the chemical constituents of kerosine, as far as he understood it compounds containing polymethylene rings were generally classed as "naphthenes" and compounds containing one or more benzene ring as "aromatics." He thought that the tendency was to consider the properties of the "naphthenes" (or "aromatics") to be more or less similar for oils of a given temperature range. It appeared to be doubtful if that was so. Hence, any argument derived from experiments on one class of bodies in one oil was not necessarily true when applied to another oil. It could be shown that naphthenes or aromatics of similar boiling point range differed widely in density and vice versa. Some naphthenes burned comparatively well, others did not. He had recorded a case where one oil of 81 per cent. naphthene content, 5·0 per cent. aromatics, 14 per cent. paraffins burned as well as one containing 40 per cent. naphthenes, 45 per cent. paraffins and 15 per cent. aromatics. The percentages of the various classes were determined by Carpenter's method (*Journ. Inst. Petr. Techn.*, 12, 555).

With reference to Table V. it appeared that the authors were not prepared to go further than saying that there was a decrease in illuminating value for an increase in boiling point. It was, he thought, possible to go a little further than that. He had experimented with two oils, one of American and the other of Eastern origin. They were examined by taking equal boiling point ranges and comparing the fractions so obtained in density, flash point, viscosity, surface tension, refractive index and candle power. In the American the percentage of paraffins increased from fraction to fraction but at a slower rate than in the Eastern. The American contained less aromatics, but the increase from fraction to fraction was slightly greater than for the Eastern. For the Eastern oil, however, the candle power decreased at a greater rate with increasing boiling point than for the American. It also gave a higher calculated density for aromatics in the higher fractions than the American. Hence he thought that it was possible to infer that aromatics contained in the higher fractions of the Eastern oil were more deleterious to burning than the high boiling point aromatics contained in the American, and that they represented aromatics of greater carbon content. He had checked that by total aromatic removal from both when the conditions were reversed, the Eastern oil decreasing at a smaller rate than the American.

He agreed with a previous speaker as to the influence of tightly or loosely woven wicks, and thought that the work of Stepanoff detailed in his "Grundlagen der Lampentheorie" was of the utmost importance in that connection. Capillary effects might be regarded as the motive force tending to drive the oil up the capillaries forming the wick. The other factor, as the authors had pointed out, was viscosity. Stepanoff assumed that the flow of kerosine between the fibres composing the wick obeyed the ordinary viscosity laws, so that the rate of flow was proportional to the fourth power of the radius of the capillary. A decrease in radius of the capillary due to closer weaving would thus have a greater effect in decreasing the supply of oil than the increase due to increased capillary rise. Thus the ideal wick would be a compromise between those two opposing factors. He thought that the bulk of the ordinary wick marketed was too closely woven for the best results. Such wicks did not give an adequate oil supply to maintain the maximum candle power of which the oil was capable. It was clear from that that if ever a lamp test was adopted in the standard methods of testing drawn up by the Institution the specification of the wick would have to receive serious attention.

He agreed with the authors that high viscosity and aromatic content were a cause of undue carbonisation of the wick, and he put forward the following explanation, which was the outcome of considerable work. High viscosity meant either, or both, high boiling point constituents, or presence of a large percentage of naphthenes and aromatics. The heat being evolved during burning varied for different parts of the flame, and the higher the viscosity or aromatic content the more heat there was being evolved at and close to the burner. Conversely, low aromatic content and low viscosity had the effect of lowering the heat evolved at and close to the burner. Hence in the former case the conditions were such as to produce greater carbonisation than in the latter. So far he had obtained no definite evidence or proof that charring was due to the formation of products of polymerisation or oxidation on the wick, but the work had only been confined to normal kerosines.

He was in complete agreement with the authors on every point regarding the fall of oil level in the container, but desired to draw special attention to the effect of the shape of the container. The ideal, as the authors had pointed out, was a constant level device, or failing that a flat, cylindrical reservoir. Fancy shapes, such as hemispherical bowls and the like, might be artistic but they were not efficient. In ordinary burning the tendency was for a constant volume of oil to be supplied per unit time as long as that

was possible. As long as that was maintained so long would the candle power remain up, so that as small as possible increase of exposed wick should take place. If, on the other hand, a gradually increasing amount of exposed wick per unit time took place, such as in a hemispherical or conical container, conditions were such as to bring about an early drop in illuminating value.

In conclusion, he would like to ask the authors how they determined aromatics. He used Carpenter's method where possible and had found that it gave consistent results. If the authors had had any experience of the method he would like to hear their views on it.

Mr. W. J. A. Butterfield said he desired to make a few remarks dealing with the question of the relationship between the sulphur content of the fuel and the bloom on the chimney. When the manufacture of carburetted water gas was introduced into this country thirty-five or thirty-six years ago the criterion of quality of gas was its illuminating value, which was tested in an Argand burner with a glass chimney. The highly purified coal gas of those days, containing on the average about 12 grains of sulphur per 100 cubic feet, did not bloom the chimneys. When carburetted water gas was burned in the same Argand burner, or a mixture of coal gas with that gas was burned, it was noticed that a considerable bloom formed on the glass chimney. That was the case whether the flame was regulated according to its height or according to its illuminating power or intensity. It was possible for anyone who was at all familiar with the subject to say whether a chimney, which had been in use for a few hours, had been used with coal gas or with a mixture of coal gas and carburetted water gas. Carburetted water gas contained, at the most, half as much sulphur as was contained in the coal gas of that date, and the bloom which appeared with the carburetted water gas could not have been due to the sulphur it contained. The bloom in question was white or very light gray, and quite different from the deposit from a smoky flame. It might not have been due to the oil, or to the gaseous products of the oil used in carburetting the water gas, but might have been due to something associated with the water gas itself. That the speaker did not know, but certainly he thought it would be rash for the authors to conclude that bloom was invariably associated with an increased sulphur content of the fuel.

Mr. S. Bowman thought the subject dealt with by the authors was eminently suitable for investigation, and as his colleagues and he had been connected with similar work for some time he desired to express his appreciation of the work the authors had carried out. From experiments he had made with various types of lamps he found that the single flat wick type gave the worst results from the

point of view of the creation of a film, and that the circular type of wick gave best results, using the same kerosine, although the consumption of oil with the circular type of wick was considerably greater. He found, however, that domestic lamps were quite unsuitable for testing the burning qualities of different kerosines, because it was impossible to get comparable results. He had therefore devised a satisfactory lamp which incorporated the essential features of a shallow vessel, a hinged burner and an easily cleaned chimney, which met the objects to be aimed at. With regard to the question of testing, he thought it was better to adopt a method which described the amount of oil consumed per candle power hour rather than merely the actual candle power. He had found it was necessary to run a test for at least 24 hours, as short tests of six hours were quite misleading. He desired to ask the authors if they had had any experience of estimating precisely the amount of film that was formed. For instance, did they possess any photographic records? With regard to the nature of the white film described, he had made a few analyses of such deposits and found in every case that 57 per cent. of SO_3 was present, equivalent to about 100 per cent. of sodium sulphate. Undoubtedly traces of ammonia were also present. The question naturally arose, where did the sodium come from? It must either come from the glass, the oil or the wick. He carried out some experiments by means of passing SO_2 and SO_3 through a lamp glass, heated up to a temperature of 250° C., which was approximately the temperature of a glass during a burning test, and in no case was a deposit formed under those conditions. He did not think the sodium came from the oil, because if an untreated oil was burned a film was still created. That left only the wick, and it was undoubtedly the case that the ash of wick contained sodium. He also wished to ask the authors if they had had any experience of a brown film—he did not mean the film obtained through smoking, but a brown film which coloured the glass an amber colour. It was rather more serious than the white film, because it cut off a greater amount of the illuminating value of the lamp. In his own investigations he found it to be characteristic of certain kerosines, but it was not yet quite clear what the actual cause was, although the presence of free sulphur was probably an important factor in the formation of the brown film. The subject was worthy of the fullest investigation, because oil was still used by an immense number of people for illuminating purposes, and also had to provide a reliable source of illumination in railway signalling systems.

Mr. E. R. Redgrove thought that interesting and valuable as the work was that had been carried out by the authors, it had been done rather late in the day, while the lamps that had been exhibited

to illustrate the lecture were the lamps of the past and not of the future. If kerosine was to be used as a source of illumination in the future he thought it must be in that type of lamp in which it was vaporised and used as a gas, being burned in the form of gas on the ordinary gas mantle principle. In a few lighthouses that he had visited that system was already in operation. He desired to ask the authors if they had made any experiments with various types of kerosine with the object of seeing whether the results obtained from illumination by vaporisation corresponded with those obtained when the oil was burned in an ordinary wick lamp.

Mr. E. Lawson Lomax desired to ask a few questions by way of a contribution to the discussion. In the first place he wished to know whether the authors had found that the same kerosine used in the same type of lamp, but with a different globe, gave different results so far as filming was concerned. While working on these lines over twenty years ago he found there was a great difference produced according to the globes that were used for the tests. The type of lamp used for the purpose of carrying out the experiments was the duplex lamp with a metal reservoir used in connection with the flicker photometer for testing the flame against the Vernon Harcourt pentane lamp. The standard lamp was fitted with a duplex burner with a fairly big capacity metal reservoir which was not too deep. On setting up four or five of those lamps and testing them with the same kerosine it was invariably found that different results were obtained with new globes. The globes were marked and changed over to the different lamps, and although there was a gradual decrease in the filming as the lamp glasses were used and cleaned, yet the filming was always of a similar degree in the same globe. It appeared to him, therefore, as if the globe had some influence on the amount of film that was formed on burning kerosine. That effect was particularly marked also if a kerosine was used that had been treated in the ordinary way with, say, 96 per cent. strength sulphuric acid, and finished with a slight treatment of Fuller's earth for brightening, giving the kerosine a sulphur content of about 0·4 per cent. Taking the same kerosine and giving it a further treatment with mono-hydrate, 100 per cent. sulphuric acid, bringing the sulphur content to about 0·14 per cent., a reduction was obtained in the filming. The same effect was, however, still obtained by the use of different globes, and it therefore struck him that the sulphur content was not wholly responsible for the filming produced by the kerosine. He further desired to ask the authors whether, in trying to evaluate a kerosine for its burning qualities, they had ever thought of taking the percentage hydrogen content of the kerosine for that purpose.

Mr. A. MacDougall said the authors mentioned a point of historical interest with reference to the question of maintaining the level of the oil constant. He believed that in 1876 or thereabouts, a patent was taken out for a lamp with an outside water reservoir and he saw it burning at the time. By this arrangement, and just as the authors had shown, the oil was kept at a constant level. Going back earlier still, he thought the members might be interested if he described a very early lamp. While carrying out some drainage work in Anglesey, at a depth of about 15 feet, he came across perhaps the oldest lamp in this country. It consisted of a spherical stone very roughly cut, with a small basin formed in the centre, possibly two inches deep, analysts actually finding traces of oil in this hollow. Rushes were used as wicks and fish-oil burned in it. In some rushlight holders a piece of resinous wood was used as a wick, which was called in Gaelic a "slute," no doubt because it gave a still more smoky flame than the earlier lamps to which Mr. Anfilogoff had referred.

Dr. W. R. Ormandy said he desired to add to his previous remarks by saying that it was a very well-known fact that all cotton took up moisture at atmospheric temperature. The amount of regain, as it was called, varied between 7 and 9 per cent.; did it influence the working of a lamp if the wick was dried out until the moisture content was nothing, i.e., if it was heated above the ordinary temperature before it was dipped into the paraffin?

Mr. J. Kewley, in reply to Dr. Ormandy, said the authors are not able to say whether the minute traces of inorganic material present in a lamp wick could be removed by soaking the wick over night in vinegar or in dilute acid to such an extent that the influence on bloom formation would be reduced; they have not so far investigated in detail the question of the influence of the wick.

In reply to Mr. Sidney T. Minchin, by "brightness" the authors in this case meant "whiteness." They agree with him in considering that the properties of the naphthenes of a given temperature range are by no means similar for various oils. This can be exemplified in many cases.

The authors agree that high viscosity generally indicates the presence of higher boiling point constituents, but they are not of opinion that high viscosity indicates the presence of a large percentage of aromatics. They have definite evidence, obtained by treating a Borneo kerosine by the Edeleanu process that the viscosity of the removed aromatic components was actually slightly lower than that of the residual components. Realising the difficulty of determining aromatics, the authors avoided this by taking for examination a series of kerosines made by blending together in varying

proportions a heavily sulphonated kerosine from a paraffin crude and the Edeleanu extract from a Borneo crude.

In reply to Mr. Butterfield, the authors regret that they cannot throw any light on the question he raised, other than the suggestion that the possible difference of temperature of the glass chimney in the two cases may have had some influence.

In reply to Mr. Bowman, the authors have used the suggested method of measuring the amount of oil consumed per candle power hour. This is a factor that depends on the properties of the kerosine in relation to the lamp in which it is burnt. The authors have not devised any method for precisely estimating the amount of bloom formed. They have found that when a lamp is burnt with a small flame, the bloom formed is enhanced, as would be expected. They have found the difficulty of obtaining constant conditions of illumination for photographing the bloom so great as to make the method unreliable.

The authors have not had sufficient experience of the quantitative examination of blooms to enable them to reply to the question of the large content of sodium sulphate. The evidence with regard to the presence of sodium is undoubtedly conflicting, but unused lamp glasses certainly do contribute some : some may also be attributed to impurities in the wick or perhaps the atmosphere. They have noticed in certain cases when burning a lamp with a low flame the formation of a brown film which gave the glass an amber colour. This film appeared to be organic in nature and had a distinctly aromatic smell. This has not, however, been further investigated.

In reply to Mr. Redgrove, the authors state that the preliminary work they have so far done showed that the variation in the character of the kerosine was of less importance in the case of vaporising lamps than in the case of ordinary wick lamps.

In reply to Mr. Lawson Lomax, the authors confirm that using the same kerosine in the same type of lamp they did obtain different results with different globes, as far as bloom formation was concerned. The authors have not used the hydrogen content of the kerosine for evaluating its burning qualities as the hydrogen content really only indicates the type of kerosine, the burning qualities being related also to the type of lamp used.

The following was subsequently received from Mr. J. A. Carpenter :—

The subject with which the authors have dealt so interestingly is of great importance in India, where the chief demand among the native population is for the cheapest possible oils for burning under comparatively primitive conditions.

Hence, a large proportion of the consumption is concerned with so-called "inferior" kerosines which contain a high content boiling over 300° C., the high viscosity and low capillarity of which bring out clearly some of the points stressed in the latter part of the paper dealing with the length of wick between the flame and oil surface.

The most widely used type of lamp in bazaars, apart from flares and torches, is the hurricane lamp in which the reservoir is shallow and the oil surface is kept so near to the flame that such lamps can be burned to exhaustion with very little variation in the height of the flame. "Tenderness" and smokiness in draughts are shown comparatively in these lamps and in all cases bear close agreement with deductions from the "Tendency to smoke" test and with the candle power given in Hinks or Saybolt lamps when the latter are kept full. In the latter types of lamp, some of these inferior kerosines will not burn at all unless the reservoir is at least half full.

Regarding the ability of wicks to carry good burning oils through lengths, there are many wicks which, when fitted to ordinary lamps, are so close grained that no differences can be observed between widely differing oils; it has been demonstrated here also that variations in ventilation so alter the combined effect of the capillarity, temperature, viscosity and rate of release by burning that complete reversals of comparison have been obtained in Hinks and Saybolt lamps.

Some experiments carried out in the Syrian research laboratory of the Burmah Oil Co. are given below and supplement the figures given in Table 7 of the paper :—

750 c.c. oil were introduced into Hinks Duplex lamps and burned for 6 hours.

For each oil Series I was carried out by adjusting the flame early to its maximum height without smoking and then leaving the wick untouched.

Series II. as for Series I., but keeping the wick turned up constantly to give maximum non-smoky flame.

Series III. similar to I., but adding oil constantly to maintain the oil level.

In each case, candle power, oil consumption per hour in grams, and length of wick between the flame and oil surface, in centimetres, are given as (1), (2) and (3) respectively.

A.—An untreated East Indian Superior Kerosine, 20 per cent. Aromatics, and approx. 30 per cent. naphthenes, 50 per cent.

paraffins; F.B.P. 290° C.; S.G. 60° F. 0·815; average b.pt. 225° C.

	I. (1) C.P.	I. (2) Cons.	I. (3) Wick length	II. (1) C.P.	II. (2) Cons.	II. (3) Wick length	III. (1) C.P.	III. (2) Cons.	III. (3) Wick length.
Initial ..	21·0	—	7·2	21·0	—	7·2	21·0	—	7·2 to 8·0
After									
1 hour. ..	21·0	85	8·2	21·0	83	8·2	21·0	83	,,
2 ,,	21·0	83	9·1	21·0	83	9·1	21·0	83	,,
3 ,, ..	20·5	81	9·8	21·0	82	9·8	21·0	82	,,
4 ,, ..	20·0	79	10·6	21·0	82	10·7	21·0	82	,,
5 ,, ..	19·0	72	11·4	20·0	81	11·6	21·0	82	,,
6 ,, ..	16·5	68	12·0	19·0	79	12·2	21·0	80	,,
Remarks:	Height of wick out of burner 3·5 mm.			Height of wick at end 7 mm. Ash 1 mm.			Height of wick 3·5 mm.		

Initial height of flame 8 cm. in each case.

B.—The same kerosine as in A. after freeing from Aromatics.

Initial ..	25·0	—	7·2	25·0	—	7·2	25·0	— 7·2 to 8·0
After								
1 hour ..	25·0	99	8·5	25·0	99	8·5	25·0	99 ,,
2 ,, ..	23·0	96	9·3	23·0	96	9·3	25·0	,, ,,
3 ,, ..	18·5	82	10·2	22·0	90	10·2	25·0	,, ,,
4 ,, ..	15·5	70	11·1	21·5	79	11·1	25·0	,, ,,
5 ,, ..	13·0	70	11·8	12·5	75	11·9	25·0	,, ,,
6 ,, ..	11·0	68	12·4	5·0	60	12·5	25·0	,, ,,
Remarks:	Height wick 5 mm.			Height wick at end 10 mm. Ash 4 mm.			Height wick 5 mm.	

Initial height of flame 9.5 cm. in each case.

C.—A refined American superior kerosine, 12 per cent. aromatics and approx. 27 per cent. naphthenes, 61 per cent. paraffins; F.B.P. 275° C.; sp. gr. 60° F. 0·805; average b.pt. 225° C.

Initial ..	22·5	—	7·2	22·5	—	7·2	22·5	— 7·2 to 8·0
After								
1 hour ..	22·5	88	8·3	22·5	88	8·3	22·5	88 ,,
2 ,, ..	21·5	87	9·0	22·0	88	9·2	22·5	88 ,,
3 ,, ..	21·0	80	9·8	21·5	87	10·0	22·5	88 ,,
4 ,, ..	19·0	70	10·6	17·5	73	10·7	22·5	87 ,,
5 ,, ..	16·0	69	11·3	15·5	63	11·4	22·5	87 ,,
6 ,, ..	13·0	60	12·0	10·5	60	12·1	22·5	86 ,,
Remarks:	Height wick 5 mm.			Height wick at end 9 mm. Ash 3 mm.			As for I.	

Initial height of flame 8·5 cm. in each case.

From series I. and II., it appears that when the wick is turned up constantly, liberation of oil by burning takes place more freely until ashing becomes considerable; this factor, operative partly through diminution of viscosity on account of higher temperatures

down the wick, is temporarily of the same order of importance as the increasing length of wick through which the oil has to travel.

The Relative Values of Aromatics, Naphthenes and Paraffins.

The illuminating power due to the presence of these classes of hydrocarbons is obviously increased under normal lamp conditions as the proportions of the first-named decrease and of the last-named increase, but experiments are in progress indicating that even paraffins of similar molecular weight may vary among themselves according to the branching of their chains. Much branching, as contrasted with straight chain hydrocarbons, brings about some slight diminution and this is more or less in line with recent published work on the wide difference in anti-knock value between n-octane and trimethyl isobutyl methane; the fundamental reasons are similar with regard to the speed of ignition but the work is not sufficiently advanced to give proofs now.

Naphthenes undoubtedly vary considerably as the following results indicate.

A "Superior" kerosine (1) was made from a Chindwin valley crude with characteristics:—S.G. 60° F. 0·825; I.B.P. 106° C.; F.B.P. 288° C.; aniline C.S.T. 58° C.; composition, 5 per cent. aromatics, 81 per cent. naphthenes, 14 per cent. paraffins.

This was compared with:—

(2) a kerosine of similar range (from another crude) solvent extracted to reduce aromatics to 5 per cent., 38 per cent. naphthenes, 57 per cent. paraffins, and (3) a Badarpur kerosine of similar range extracted to contain 5 per cent. aromatics, 90 per cent. naphthenes, 5 per cent. paraffins.

It was found that (1) burned quite as well as (2) and that (3) was hopeless.

Investigations into chemical and physical nature of the naphthenes as far as could be carried out suggested that the naphthenes, in (1) were cyclo-pentane derivatives with long open side chains almost like paraffins, while the Badarpur naphthenes were polynuclear of the type of naphthalene and terpenic derivatives; those in (2) were of mixed types.

From another series of experiments, subject to reservations depending on the matter in the last paragraph, it appears that a fair indication of the burning properties of a kerosine is given by the aniline C.S.T. If a cracked kerosine is being considered, the C.S.T. of the product produced by treatment with three volumes of 83 per cent. sulphuric acid followed by redistillation to the original F.B.P. gives indications for the saturated portion (as in

Egloff and Morrell's method for the determination of unsaturateds in cracked spirits).

The higher the C.S.T. for a given boiling range, the better is the illuminating power and freedom from smoke under ordinary lamp conditions.

Incidentally, the method employed for determining the proportions of aromatics, naphthenes and paraffins in a kerosine (if cracked, after treatment as above) is based on data given in this Journal, 1926, 12, pp. 544-567 :—

The *average* boiling point of the kerosine is deduced from the distillation analysis and the aniline C.S.T. of the pure paraffin boiling at this temperature is noted from the data comprising the top curve in Fig. 2 of the paper quoted. The C.S.T's. given by the kerosine before and after treatment with three volumes of 98-100 per cent. sulphuric acid are then taken and the aromatic content is deduced therefrom.

As each 1° C. depression in the aromatic-free portion corresponds roughly to 5 per cent. naphthenes, the result is easily deduced, e.g., if the average b.pt. pure paraffin had a C.S.T. of 80° C., while the acid treated kerosine had one of 76° C., the aromatic-free portion would contain $(80—76)\times5=20$ per cent. naphthenes and 80 per cent. paraffins. If the aromatic content had been found to be 10 per cent., the total composition would then be 10 per cent. aromatics, 18 per cent. naphthenes and 72 per cent. paraffins.

The kind permission of the directors of the Burmah Oil Company to quote the experimental data is acknowledged.

Kerosine and its Uses.*

By Walter A. Woodrow, A.I.C., F.C.S. (Member).

Kerosine is the term usually applied to the product obtained by the distillation of crude pertoleum which boils between 150–300° C. It is a mobile liquid, usually pale straw to water white in colour with odour varying with the country of origin.

It does not follow, however, that such fractions from all crudes are suitable for the ordinary uses of kerosine, as, for example, products from Rumanian fields will burn satisfactorily only in lamps of the "Cosmos" type, and certain Eastern oils can only be used in lamps with abnormally high chimneys, also because of the tendency to smoke.

Other types, such as Scotch and Canadian oils, are unsuitable for use by themselves for domestic purposes in this country owing to their unpleasant odours; the former, however, is widely used commercially and the latter locally.

The best types of burning oils are obtained from large producing countries such as America, Mexico, and Persia. Other types, such as Russian and Californian, are more widely used for power purposes.

The following analysis will illustrate the differences in kerosines from various sources:—

	Texas.	Persian.	Rumanian.	Russian.
Specific Grav. @ 60°F.	0·806	0·7941	0·818	0·822
Closed Flash Pt. °F.	110	93	94	84
Colour	Plus 21	Plus 23	Plus 17	Plus 17
Initial Boiling Pt. °C.	163	152	141	135
	%	%	%	%
Distillate @ 150°C.	—	—	5	5
160	—	4	10	13
170	3	15	19	23
180	8	31	29	31
190	17	43	38	39
200	27	55·5	46·5	46
210	38	64·5	54	53
220	47	73	63	60
230	59	80	71	67
240	68	86	77	74
250	77	91	82	80
260	85	94	87	85
270	90	96	91	90
280	93	—	93	93
290	—	—	95	95
300	—	—	98	98
Final Boiling Pt.	298°C.	281°C.	Over 300°C.	Over 300°C.

* Paper received June 13th, 1927.

The uses to-day for kerosine are many and include the following:—

1. ILLUMINATION.—The subject of the use of kerosine for illumination in domestic lamps has been adequately dealt with by Messrs. Kewley and Jackson in their paper as published in the present journal, but it is of importance to mention a further use for kerosine as an illuminant, viz., in railway signal lamps. The kerosine for this purpose must be of very high quality to be able to burn satisfactorily for the long periods required for signal work, which may range from one week to one month, during which period the size of the flame should not diminish unduly. This is attained by removing from the kerosine by careful refining any constituent likely to cause excessive crust formation on the wick. It is also necessary to remove products likely to produce smoking, which would cause "sooting" of the lantern, with subsequent loss of brilliancy.

Signal oil is burned in lamps with burners of special construction, such as the "Welch," "Adlake," and "Barton." It is hardly necessary to enter here into the details of each burner, except perhaps to mention the variations in the wicks employed.

(*a*) *The "Welch" Burner.*—This pattern has a circular wick of tightly plaited cotton, and it is found necessary to employ an additional "feeder" wick of loosely plaited cotton, which augments the supply of oil to the main wick.

(*b*) *The "Adlake" Burner* also has a circular wick, but one made of felt stitched round a core of cotton strands. Both of the types mentioned give a "cone" or "pencil" shaped flame which is usually very steady and behaves admirably for laboratory testing of this type of kerosine, also for actual use on railways.

(*c*) *The "Barton" Burner.*—This type has the usual flat kind of cotton wick giving obviously a flat flame. This burner has seen a lot of service in the past on some of our principal railways, but to-day the "Welch" and "Adlake" are more generally used.

2. EXTRACTION OF NAPHTHALENE FROM COAL GAS.—Kerosine is employed in some places in preference to ordinary coal tar naphthas as a solvent for naphthalene from coal gas owing to its being obtainable at a more reasonable cost and also to its possessing the great advantage of containing no naphthalene whatever.

When the solvent is introduced into the mains, the first essential is to ensure that it will carry effectively throughout the whole system, and to this end the kerosine must be completely atomized and not vaporized, as it has a comparatively low vapour pressure,

and if vaporized will not remain in the gas for any length of time. The solvent, i.e., kerosine, should therefore be present in the mains in the form of a fine mist.

3. INSECTICIDES.—Kerosine is the fraction of petroleum used more widely than any others against insects which ravage plants. It may be used (a) pure; (b) in the form of an emulsion with soap—for preference whale oil soap—and (c) in the form of an emulsion containing salts, like arsenite of copper, and in many other forms.

The kerosine or emulsion should be applied in the form of a fine mist capable of touching the whole surface of the plants without moistening it, and the application should be made in dry warm weather so that evaporation takes place immediately to avoid injuring the plants.

4. OIL ENGINE FUEL.—Kerosine is used extensively as fuel for stationary engines, tractors and motor boats. The types used vary considerably, some having boiling points of 145–240° C. with reasonably low flash points of 80–90° F., others are more of the usual type of kerosine having boiling points between 150–300° C. and flash points of 120–140° F. Kerosines are selected to suit different engines, and it is necessary to adjust the compression of an engine when changing over from fuel of one origin to another, for example: American to Russian, to enable the maximum efficiency to be obtained.

5. INCUBATOR WORK.—Kerosine is widely used as a source of heat in incubator work, the oil being burnt in a specially constructed lamp and lantern known as the "Hearson" Patent Spring Lamp. The oil must be of such good quality to ensure a steady flame, absence of odour and minimum char. It is interesting to mention that the regular temperature which must be maintained for at least three weeks is controlled by a special construction in the incubator called the "Hearson Thermostatic Capsule," which contains a liquid which vaporizes at a fraction of a degree below the temperature required for the hatching, and immediately the heat radiated by the water tank of the incubator raises the egg-chamber temperature to even one-tenth of a degree more than is required, the capsule expands and in so doing actuates certain mechanism which eventually raises the damper and allows the heat to pass out of the chimney to air instead of through the flue (which passes through the water tank) until the temperature is corrected.

6. HEATERS.—The use of kerosine in "heaters" is a mark of progress of "portable" heating, the oil being burnt in specially

constructed stoves which can with every safety be transferred from one room to another.

The kerosine for this purpose must be of good reliable brand and practically free from sulphur, thereby cutting out the possibility of unpleasant odours during combustion of the oil. It is often noticed when inferior kerosines are used that a distinct "sharp" or acid flavour is imparted to the atmosphere, which is obviously undesirable.

7. Cookers.—The introduction of the modern oil cooker has proved a boon to the country house where sources of heat such as electricity and coal gas do not exist, such difficulties being overcome by the easy transportation of kerosine to any remote part of the country.

Again, kerosine for this purpose must be of similar good quality as required for use in heaters to effectively avoid the possibility of production of odours during use.

The oil is burnt in a specially constructed burner, by means of which additional air is supplied to wick, producing a blue-edged flame which ensures that the maximum calorific value is obtained from the kerosine.

Burning Tests of Kerosine.*

By W. H. Thomas, A.R.S.M. (Associate Member).

Very little has been written recently on the subject of kerosine, particularly with regard to its uses as an illuminant, but, on the other hand, much has yet to be learnt concerning the phenomena occurring during the burning of kerosine from a wick.

Practically any type of kerosine can be burnt satisfactorily as an illuminant, provided that the lamp is of a suitable design for the oil concerned. An oil of paraffin base will burn well in almost any type of modern lamp, but naphthenic oils or those obtained from a crude oil rich in aromatic hydrocarbons require a burner in which proper combustion is brought about by an ample and well-directed current of air.

Unsatisfactory burning of kerosine in a lamp invariably results in a lowering of the candle power and can be caused by a great number of widely differing faults. Firstly, the kerosine may be unsuitable for the lamp and the latter may be of faulty design or insufficiently cleaned. Again, if the oil has not been refined sufficiently or properly it will fail to give satisfaction as an illuminant. The presence of aromatic or olefinic hydrocarbons causes the flame to be smoky in addition to giving it a distinctly red tinge. Sulphur compounds, such as alkyl sulphides, derivatives of thiophene, etc., cause a bad odour during combustion. Derivatives of sulphuric acid cause undue charring of the wick and in conjunction with the sodium salts present in the wick, a white film consisting mainly of sodium sulphate is formed on the lamp glass. Mineral salts will cause incrustation of the wick and subsequent clogging of the wick capillaries. If the distillation test of a kerosine covers a wide range extending above 300° C., the flame will be very liable to drop considerably, sometimes to only one-half of its original height. Again, if the diameter of the reservoir be too small, the level of oil will fall too rapidly, and the capillary power of the wick will be quickly overtaxed. An oil cannot be expected to burn satisfactorily if the wick is inferior in make or unsuitable for the burner. It is frequently not realised that moisture seriously interferes with the flow of oil up the wick and the accumulation of only a little water in the reservoir is sufficient to make the combustion unsteady and the flame variable. The temperature at which the oil is supplied to the wick naturally affects the burning

* Paper received June 15th, 1927.

qualities of the oil, especially as regards combustion and the height of flame. It is interesting to note here that flat wicks are more popular in the British Isles and America, while circular wicks are more used on the Continent. The capillary attraction exerted by a wick determines its value. A tightly-woven wick consisting of relatively "short-staple" cotton is very much inferior to one of loosely-woven texture made of "long-staple" cotton. Redwood[1] has shown that with flat wicks of the same width, in ordinary use, there was a variation in the proportion of 1:2·5 in the quantity of oil raised under similar conditions. It is further stated that wicks were found to absorb from 4 to 6 per cent. of their weight in moisture from the atmosphere. It is obvious, therefore, that wicks should be carefully washed and dried before use in order to take full advantage of the maximum capillary power. Hamor and Padgett[2] state that the rise of kerosine in the capillaries of a wick is determined by the surface tension that the oil exerts therein. The flow of oil through a wick has been investigated by Stepanow[3], the results of the investigation being expressed by the equation :—

$$Q = A\frac{a^3}{Z}$$

when

Q = volume of oil drawn to a certain height through the wick.

a = capillary constant of the oil.

Z = viscosity of the oil.

A = factor involving the specific gravity of the oil.

As the upper portion of the wick is heated by the metal of the burner, the variations in capillary constant and viscosity of a kerosine are of considerable importance. Both of these properties decrease with rise of temperature, the viscosity showing the greatest change.

Now, although the petroleum industry is not directly concerned with the proper design of lamps and their fittings, nevertheless, it is important to produce a material which will burn satisfactorily in an ordinary household lamp for periods of at least 8 hours. Various methods of carrying out burning tests on kerosine have been devised, but few have proved to be entirely satisfactory owing to the difficulty of carrying out each test under absolutely identical conditions.

The original Saybolt testing lamp consisted of a tall graduated glass vessel fitted with a flat wick burner, the latter giving a flame

[1] "A Treatise on Petroleum" (Redwood).
[2] "The Examination of Petroleum" (Hamor and Padgett).
[3] "Grundlage der Lampentheorie" (Stepanow).

of considerable height compared with its width. The chimney was about the same size as the reservoir and was graduated in order to enable flame heights to be taken. A specially selected wick was used and the lamp was burned with the reservoir immersed in a bath of water maintained at 60° F. The test consisted essentially of measuring the depression of oil level, and the diminution of the height of the flame after a specified period of time.

The Canadian method of carrying out a burning test consisted of determining a "burning percentage." The lamp reservoir was a bowl of 4 in. diam. and $2\frac{3}{4}$ in. in height with a neck of such a size that the top of the wick was 3 in. above the bowl. The burner was of the "Sun-hinge" type and accommodated a wick $\frac{7}{8}$ in. in width and $\frac{1}{8}$ in. in thickness and a chimney 8 in. long. The

FIG. 1.

reservoir was filled with oil and the lamp weighed and lighted. The flame was turned up to a position just below its smoking point and allowed to continue burning until 12 oz. of oil were consumed. The amount of oil burnt during the first and last hours was noted, the ratio of the two quantities being a measure of the burning quality. The percentage of the last hour's consumption of the first hour's was taken as the burning percentage. In Redwood's method of carrying out burning tests, stress is laid on an examination of the

wick. The wicks are examined by a special capillarity apparatus and any defective portion rejected. The height of travel of an oil of known quality up to the wicks is measured at a fixed temperature (60° F.), three or more sections of the same type of wick being tested simultaneously. Any wick of poor capillarity can thus be detected before carrying out the burning test. For the test, oil reservoirs of uniform dimensions are used, and the burners are first tested to ensure that similar flames can be obtained using the same oil. The wick is dried before use and immersed in the oil while still warm, and then carefully trimmed. The oil in the reservoir is kept at 60° F. and the flame raised to the highest point possible

FIG. 2.

without smoking taking place. A camera is used so that the outline of the flame can be traced at intervals on thin paper.

The modern Saybolt Testing Lamp adopted by the American Society for Testing Materials is of course very well known and any detailed description is unnecessary here. The main outlines of the apparatus and the method of carrying out the test are as follows :—

The reservoir is cylindrical and stands on a suitable base, while the burner is of the flat wick type with the top of the spreader hinged in order to facilitate trimming of the wick. The lamp glass is of special shape, and in height is almost equal to that of the lamp, minus the burner. In order to carry out a test, 850 cubic centi-

metres of oil are charged into the reservoir and the wick trimmed so that the flame is 1¾ in. high (measured from the top of the wick guide) and 1¼ in. wide measured at the widest part. The lamp is weighed at the end of the first and second hour's burning, and from the weights obtained the consumption per hour is calculated. The normal consumption is 43 cc. per hour. The burning is continued for a period of 24 hours, the reservoir being refilled at intervals of eight hours, without extinguishing the flame. Flame measurements are made by means of the "Rather Burning Test Gauge," which consists essentially of two pairs of slotted arms adjustable by means of two screws along a graduated scale. With the arms in a

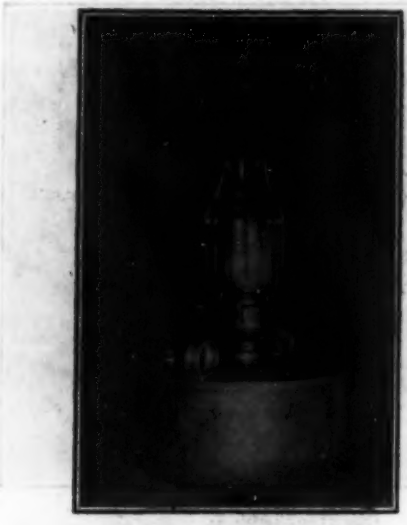

FIG. 3.

horizontal position, the slots in the lower pair of arms are brought in line with the top of the wick holder by means of the adjusting screw. The upper pair of arms are then moved until the slots coincide with the average height of the flame. The flame height can then be measured on the graduated scale. In order to measure the flame width, the arms are placed in a vertical position, and a similar procedure carried out. It is frequently found that the chief drawback of the Saybolt lamp is its relatively high consumption (43 cc. hour) which necessitates attention three times during 24 hours. The lamp can therefore only be used in laboratories

where shift work is operative. Self-filling devices can of course be used, but this complicates the apparatus required for the test.

The following description is of a lamp which has been found to give complete satisfaction both for burning tests and for photometric observations. It was developed with a view to simplicity of design allowing of exact duplication and ease of cleaning and also with a view to obtaining a lamp glass properly suited to the burner, whereby comparable results could easily be obtained. The reservoir of the lamp is cylindrical in shape and very slightly domed at the top, the diameter being 6½ ins., the height 3 ins., and the top of the dome ¼ in. above the upper edge. The lower portion of the burner slides into a brass sleeve situated in the centre of the top

Fig. 4.

of the reservoir. The burner is 2 ins. in height and is constructed of stout brass, while the flame spreader or dome is hinged so that it can be turned back to allow of the proper trimming of the wick. In plan, the wick-holding portion of the burner is ⅝ in. long by ⅛ in. wide, and accommodates the normal type of best quality ¾-in. wick.

The total height of the glass chimney is 7½ ins., the base is 1¾ in. diameter, and the top 1¼ in. diameter. The accompanying photographs will give some idea of the lamp and its fittings, and also of the shape of flame when tests are being carried out.

In order to prepare the lamp for a burning test 900 cc. of oil are placed in the reservoir and the burner fitted with a freshly dried wick. A dry lamp glass, previously cleaned with soap and water and distilled water, is then fitted to the burner and turned back on the hinge, together with the flame spreader, in order to expose the wick-holding portion for trimming. It is important to use lamp glasses which have already been used at least six times, as new glasses have always been found to give rather inferior results, due possibly to the presence of small quantities of sodium salts on the surface of the glass. The trimming of the wick is carried out by means of a sharp pair of scissors, the corners of the wick being cut until the desired shape of flame is obtained. It has been found very convenient to use the Rather Burning Test gauge, in order to adjust the flame to a height of 1 in. and a width of 1 in. When the flame is properly adjusted the lamp is allowed to burn continuously for 24 hours in a well-ventilated but draught-proof room. At the end of the first hour's burning the dimensions of the flame are checked, after which time no further adjustments are made. A determination of candle-power is then carried out. Similar measurements of flame dimensions and candle-power are made at the end of the test, together with a determination of candle-power, using a clean lamp glass. The difference between the two candle-power readings will give a measure of the intensity of the film on the lamp glass. If it is convenient, check determinations should be carried out at least four or five times during the test, in order to note any undue variation of flame or candle-power. At the end of the test it is a simple matter to compute the diminution of the size of the flame, the consumption of oil per hour, and the output of illumination (in candle-power hours per cubic centimetre of oil). After extinguishing the flame, the volume of unburnt oil should be measured in order to determine the total consumption, the condition of the wick should be noted, and the film on the lamp glass should be described. The latter description should include the colour and type of film, and the disposition of the film on the chimney. The film usually consists of a mixture of brown and white deposits; the latter has been proved to consist mainly of sodium sulphate, while the former might conceivably be composed of a complex asphaltic polymerisation product due to slight decomposition of the oil on the edges of the flame and the subsequent volatilisation of the product on to the side of the chimney. The white film is probably caused by the combination of the sodium salts present in the wick with the sulphur present in the oil. The normal consumption of oil, with a flame 1 in. by 1 in., is about 27 cc. per hour, while the degree of illumination varies between 5 and 6.5 international candle-power. These measurements of

candle-power are naturally taken with the broadest part of the flame at right-angles to the length of the photometer bench. If, however, the flame be placed "edgeways-on," the diminution of apparent candle-power is in the order of 1 to 1.5 candle-power. Obviously, therefore, the thickness of the flame exerts a marked influence on the intensity of illumination. If this were not so, then the ratio of the candle-powers would be equal to the ratio of the flame areas. It will be realised that if all the above observations and calculations are made, a very accurate assay of the burning qualities of an illuminating oil can easily be obtained.

The writer usually determines candle-power by means of the normal Bunsen photometer fitted with an efficient photometer head of the "Lummer Brohdun" type and a "Hefner" amyl acetate lamp of 1.11 international candle-power. By this method the mean horizontal candle-power is determined.

In connection with the determination of candle-power the writer would like to draw attention to a paper recently published by the Department of Scientific and Industrial Research, and entitled, "The Measurement of Mean Spherical Candle Power." Here mention is made that, in the new electric lamp specification, the British Engineering Standards Association has adopted a candle-power figure which is a measure of the total light output of the lamp, in place of the mean horizontal candle-power figure previously used.

This average value (the mean spherical candle-power) may be found by measuring the candle-power in a large number of directions equally distributed in space about the source as origin. Alternatively the conception of "luminous flux" may be introduced. It is stated in the latter connection that a finite amount of luminous energy can be emitted by a source only within a finite solid angle from that source in the direction considered. The time rate of flow of luminous energy is called the "luminous flux," and its unit is the "lumen." The normal unit of candle-power and the lumen per unit solid angle are exactly equivalent.

Here, then, is a more exact method of determining total candle power, but whether it could be applied to burning test lamps is a matter which can only be decided by experiment.

The foregoing paper is not intended to cover every method of carrying out burning tests, but it is hoped that an indication will be given of the main lines of procedure, which are most suitable for the carrying out of a critical burning test.

The writer is indebted to Mr. R. Pitkethly for his careful preparation of the photographs.

Long Time Burning Oil.*

By S. Bowman, F.I.C. (Member).

The function of long time burning oil is clearly indicated by its name which distinguishes it from the ordinary grade of kerosine or lamp oil used in domestic lamps for comparatively short periods without attention.

Perhaps one of the most important uses of long time burning oil is that for railway signal illumination, where, owing to difficulties in distribution electricity cannot satisfactorily be used.

It is interesting to note that in the early days of railways, night signalling was effected by raising and lowering a glowing bucket of coals, but this system was soon replaced by oil lamps burning mineral or vegetable oils. At that time these lamps required daily attention for the purpose of filling, trimming, and lighting, and it soon became apparent that if a lamp could burn continuously for a number of days without attention, the saving in labour costs would be considerably greater than the cost of oil consumed during the daylight hours.

Various types of lamps were introduced for this purpose the essential features of which were a wind proof case giving satisfactory ventilation. To the refiner fell the task of producing an oil which would burn continuously in these lamps for prolonged periods, his only experience being the production of kerosine, which is seldom required to burn for longer periods than eight hours without attention. In this country, railway signal lamps are usually in continuous operation for 7-14 days before being changed, while in America 28 days is standard practice, and the fact that this class of oil has been observed to burn continuously for 67 days[1] is a good indication of the progress made in the refining of this fraction of petroleum.

The conditions under which signal lamps are required to operate are always rigorous, being exposed to varying climatic changes and excessive vibration, and this with a flame so small to be exceedingly sensitive. It will therefore be realised that the factors of char formation and tendency to smoke acquire an important significance in refining an oil for this purpose and the one time belief that a satisfactory long time burning oil could only be produced from a sulphur-free paraffin base crude is readily understood. Modern refining, however, can and does produce this class of oil from all types of

* Paper received June 17th, 1927.

[1] H. E. Morgan, F. J. Hookham, Proc. Inst. Railway Signal Engineers, 1925–6.

crudes, but the refiner of a paraffin crude certainly has an initial advantage.

The characteristics of an oil required for wick-fed lamps have been fully dealt with in a paper by Kewley and Jackson* and the most important of these governing the properties of long time burning oil are:

(*a*) Formation of char,

(*b*) Tendency to smoke,

(*c*) Rate of consumption.

Dealing with these in turn: (*a*) is undoubtedly the result of several factors some of which are still more or less obscure. Thermal decomposition or cracking of the oil is certainly one cause of char and as the heavier fractions are less stable to heat the necessity of limiting the heavy ends or tails in this fraction is obvious. The action of sulphur is not so clear although it can easily be demonstrated that the addition of this element, particularly in the free state shows a decided increase in char formation and deterioration of the wick fibres. In any case the sulphur content of an oil affords a good index of refining if the origin is known. On the other hand, the absence of this element does not necessarily denote a satisfactory product, as for example a mixture of white spirit with paraffin liquidum, both highly refined fractions, can be made to possess certain characteristics similar to long time burning oil, yet such a mixture will not burn for more than a few hours owing to excessive char formation.

(*b*) Tendency to smoke is governed chiefly by the aromatic content, which hydrocarbons have no useful purpose in any illuminating oil used in wick-fed lamps. A large percentage of the lighter fractions of paraffins may also cause a tendency to smoke owing to the rapid decrease in viscosity on rise in temperature and consequent increased volatility.

(*c*) Rate of consumption is an important factor, because however small the amount of char may be, the failure of the lamp through lack of oil is no less serious and the margin of safety afforded by the capacity of signal lamp reservoirs is not always as much as it might be.

The rate of consumption is dependent on the volatility of the oil and as this usually coincides with a low viscosity the lighter fractions have a tendency to burn much more rapidly. On the other hand, the heavier fractions burn more slowly but produce more char, so a compromise must be made and the ideal long time burning oil should possess as narrow a boiling range as possible having regard to specification requirements.

* This journal, pp. 364–382.

Needless to say an oil that is required to function in a signal lamp for prolonged periods is particularly sensitive to the presence of adventitious matter. Cases are known where traces of glue and resin from barrels have been fatal to the burning properties and it has also been found that the dye (Sudan III) used for tinting the oil, was deleterious if present in a greater concentration than 1 : 10,000.

Oil for long time burning signal lamps is always required to conform to certain specifications, a typical example of which is quoted as follows :—

> "The oil to be genuine petroleum of the finest quality, water white and free from acidity, suspended matter and water. Specific Gravity at 60° F. not to exceed 0·820. Flash Point (closed) to be not below 110° F. When 100 c.c. are distilled from an Engler flask the amount of distillate should not be more than 2% at 180° C. and not less than 92% at 280° C.; distillation should be completed at 300° C. The oil supplied must burn satisfactorily in a signal lamp for ten days without attention."

These specifications differ according to the various company's requirements, particularly with regard to the type of lamp employed for the burning test. This matter has, however, been receiving the attention of the Standardization Committee of the Institution of Petroleum Technologists, and a standard method of procedure will probably be available in the near future.

Contribution to the Knowledge of "Berginisation" and a Study on the Technical Chemical Investigation of Hydrocarbon Mixtures. Part I.

By H. I. Waterman, Ph.D. (Member), and J. N. J. Perquin.*

This work is a continuation of an investigation on the nature of liquid reaction products obtained from the action of hydrogen on paraffin wax under high pressure.[1] The identification of the hydrocarbons was previously tried as much as possible in a physical way. Very careful and extensive fractional distillation, combined with the determination of the specific gravity, refraction and bromine number (McIlhiney method) of the fractions, gave very important indications regarding the processes occurring during Berginisation of paraffin wax.

The physical research has now been extended by a more complete refractometric analysis; at the same time more attention has been given to the determinations of molecular weight by the micro method of Rast[2] for the solid products and by the Victor Meyer method for the lower boiling fractions. The general significance of the refractometric research is demonstrated chiefly by the investigations of Eykman,[3] and French investigators have recently laid special stress on the applications of refractometry in the research of petroleum products.[4] Darmois found $\frac{\Delta n}{a}$ rather constant for hydrocarbons of the same series, Δn being the difference of the refraction for two different wave lengths, *e.g.*, the rays α and γ of the hydrogen spectrum, and d representing the specific weight determined at the same temperature as the refraction. Thus, he found for cyclohexane, $(155)10^{-4}$; pentane, octane and isodecane, $(156—157)10^{-4}$; amylene, $(194—204)10^{-4}$; methylcyclohexene, $(191)10^{-4}$; aliphatic hydrocarbons with two double unions, C_5, C_6 and C_7, $(220—230)10^{-4}$; benzene, $(298)10^{-4}$; toluene, $(300)10^{-4}$; etc.

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* Paper received May 23, 1927.

[1] H. I. Waterman and J. N. J. Perquin, *Journ. Inst. Petr. Techn.*, 1925, **11**, 48; H. I. Waterman and A. F. H. Blaauw, *Rec. trav. chem.*, 1926, **45**, 284.

[2] *Ber.*, 1922, **55**, 1051.

[3] A. F. Holleman, "Recherches réfractométriques de feu." J. F. Eykman, "Natuurkundige Verhandelingen van de Hollandsche Maatschappij v. Wetenschappen te Haarlem," Deel **8**, 1919, Haarlem, De Erven Loosjes. See also F. Eisenlohr, "Spektrochemie organischer Verbindungen," Stuttgart, 1912.

[4] G. Dixmier, "Sur l'utilisation des dispersions de réfraction dans l'identification et l'analyse des essences," *Chim. et Ind.*, Sept, 1926, **16**, 3.

Working with commercial products, which, from the boiling-points given, might be considered as mixtures, for instance, the amylene used had a boiling range of 29° to 35° C.,[5] Dixmier believes that his "specific dispersion" is a pure additive property in mixtures of benzene and cyclohexane and in more complicated mixtures of benzene, toluene, methylcyclohexane and heptane.

The refraction and dispersion for a large number of hydrocarbons obtained from different firms have been determined and the results are given in Table I. It is seen that the preparations from different sources vary widely, while some products are very impure. The readings obtained with heptane No. 1 indicate that this product was very impure, as are also octane Nos. 8 and 17. Octane No. 16 is probably rather pure, its dispersion $(n_a^1-n_c)10^4$ being 110. Eykman[6] found for a sample from Kahlbaum, which was afterwards purified and finally rectified on sodium, boiling-point 125° C. at 752 m.M.; d_{vac}, 0·7019 at 20·6° C.; $(n_a^1-n_c)10^4$ at 20·6° C., (1·40692—1·39599)10^4=109·3. Eykman[7] found for the dispersion, $(n_a^1-n_c)10^4$, of isopentane at 14·2° and 19·1° C., 97·4 and 96·9; for normal hexane at 15·45° C., 103; for diisoamyl at 13·1° C., 114·5. It is seen that isopentane No. 13, *n* hexane No. 15 and diisoamyl No. 18 also have dispersions which differ very little from the values given in literature. The absolute value of the refractive indices of isopentane No. 13, hexane No. 15, octane No. 16 and decane (diisoamyl) No. 18, also differ little from those given in literature. This pleads for the purity of these products. On the contrary, the same optical constants indicated that various other hydrocarbons in Table I. were undoubtedly very impure (hexane Nos. 3 and 14, heptane No. 1, octane Nos. 17 and 8).

The dispersion values of amylene, Nos. 6 and 7, and octylene, No. 11, agree very well with those given in literature. The absolute refraction values of amylene No. 6 and caprylene No. 11 are different from those of Eykman and these products are, therefore, undoubtedly impure.

The dispersions of the cyclohexanes and of the methylcyclohexanes agreed with Eykman's values, while those of dimethylcyclohexane No. 23 are rather high, as are also the absolute refraction values. The dispersions of cyclohexene No. 5 and methylcyclohexene (para) No. 4 agree with Eykman, the absolute refraction, however, giving a small difference. The dispersion and absolute refraction values of cymene agree with those mentioned

[5] See also J. F. Norris and J. M. Joubert, *J. Amer. Chem. Soc.*, 1927, **49**, 873.

[6] *Chem. Weekblad*, 1906, **3**, 655.

[7] A. F. Holleman, *loc. cit.*

TABLE I.

Refraction and Dispersion of Hydrocarbons.

Hydrocarbon and Origin.	Temperature, ° C.	n_C	n_D	n_F	n_G^1(434)	$(n_G^1-n_C)10^4$	$\frac{(n_G^1-n_C)\ 10^4}{n_D-1}$
Pentane No. 2 (de Haen)	8·2	1·3625	1·3644	1·3687	1·3726	101	277
	10·4	1·3613	1·3631	1·3676	1·3712	99	272
Pentane, normal, from petroleum, No. 12 (Poulenc)	10·4—10·35	1·3581	1·3603	1·3642	1·3678	96	266
Isopentane No. 13 (Poulenc)	10·4	1·3577	1·3594	1·3631	1·3669	92	256
Hexane, normal, from propyliodide, No. 15 (Kahlbaum)	10·85—10·9	1·3778	1·3796	1·3842	1·3881	103	272
Hexane, normal, from petroleum, No. 3 (Poulenc)	10·3—10·2	1·3893	1·3913	1·3961	1·3993[5]	100	256
Hexane, from petroleum, No. 14 (Schuckardt)	10·9	1·3895	1·3915	1·3965	1·4006	111	283
Heptane, from petroleum, No. 1 (Schuckardt)	10·4	1·4011[5]	1·4033	1·4084	1·4125	114	283
	8·1	1·4024	1·4046	1·4097	1·4140	116	287
Octane, normal, from octyliodide, No. 16 (Kahlbaum)	10·8	1·3997	1·4019	1·4063	1·4107	110	274
Octane from petroleum, No. 17 (Schuckardt)	10·8—10·4	1·4205	1·4232	1·4286	1·4331	125	295
	11·2—11·5	1·4204	1·4228	1·4282	1·4331	126	298
Octane, from petroleum, No. 8 (Schuckardt)	10·2—10·5	1·4176	1·4199	1·4255	1·4301	127	302
	11—11·4	1·4168	1·4194	1·4247	1·4293	125	298
Decane, diisoamyl, No. 18 (Kahlbaum)..	10	1·4113	1·4133	1·4184	1·4228	115	278
Amylene, No. 6 (Poulenc)	10·5—10·4	1·3907	1·3933	1·3992	1·4045	138	351
Amylene, No. 7 (Kahlbaum)	10·5—10·6	1·3894	1·3922	1·3982	1·4037	142	362
Caprylene, No. 11 (Schuckardt)	10·3—10·45	1·4200	1·4226	1·4288	1·4340	140	331
Cyclohexane, No. 19 (Kahlbaum). ..	8·25—8·3	1·4303	1·4326	1·4378	1·4423	120	277
	10	1·4294	1·4315	1·4369	1·4414	120	278
Cyclohexane, No. 20 (Poulenc)	10·1—10·2	1·4293	1·4314	1·4368[5]	1·4412[5]	120	278
Cyclohexane, No. 9 (Schuckardt) ..	9·8—10·2	1·4287	1·4315	1·4362	1·4406	119	276
Methylcyclohexane, No. 21 (Schuckardt)	10·2	1·4260	1·4280	1·4336	1·4382	122	285
Dimethylcyclohexane 1 : 3, No. 22 (Poulenc)	10·2—10·15	1·4276	1·4300	1·4350[5]	1·4399	123	286
Dimethylcyclohexane 1 : 3, No. 23 (Schuckardt)	10·1—10·15	1·4308	1·4333	1·4387	1·4435	127	293
Cyclohexene, No. 5 (Poulenc)	10·3—10·35	1·4505	1·4534	1·4601	1·4659	154	340
Methylcyclohexene (para), No. 4 (Poulenc)	10·2—10·3	1·4500	1·4529	1·4594	1·4650	150	331
Benzene (free from thiophene), No. 26 ..	10·8	1·5008	1·5057	1·5175	—	—	—
	10·5	1·5009	—	1·5177	1·5280	271	536
Benzene (free from thiophene), second sample	8·4	1·5024	—	1·5192	1·5297[5]	273	—
Cymene, No. 25 (Poulenc)	10·3—10·35	1·4903[5]	1·4943[5]	1·5045	1·5132	229	463
Tetraline (Tetralin Ges.), No. 24 (Rodleben)	10·2	1·5480[5]	1·5531	1·5657	—	—	—

TABLE II.

Hydrocarbon and Origin.	n_C	n_D	n_F	n_G^1(434)	$(n_G^1-n_C)\ 10^4$	$\frac{(n_G^1-n_C)\ 10^4}{n_D-1}$
Pentane, No. 40 (Kahlbaum, brown label)	1·35244 (20·3°)	1·35424 (20·2°)	1·35855 (20·35°)	1·36202 (20·35°)	95·8 (20·35—20·3°)	270
Hexane, normal, from propyliodide, No. 41 (Kahlbaum)	1·37290 (20·2°)	1·37480 (20·35°)	1·37934 (20·4°)	1·38306 (20·3°)	101·6 (20·3—20·2°)	271
Caprylene, Symm. methyl-n. amylethylene, No. 43 (Kahlbaum, new sample)	1·41120 (20·15°)	1·41361 (20·3°)	1·41986 (20°)	1·42494 (20·2°)	137·4 (20·2—20·15°)	332
Hexadecene, No. 42 (Kahlbaum, new sample)	1·43897 (20·15°)	1·44135 (20·25°)	1·44725 (20·1°)	1·45225 (20·1°)	132·8 (20·1—20·15°)	301
Paraxylene, No. 35 (Kahlbaum)	1·49162 (20°)	1·49607 (20°)	1·50716 (20°)	1·51716 (20°)	255·4 (20—20°)	513
Metaxylene, No. 34 (Poulenc)	1·49095 (20°)	1·49540 (20°)	1·50630 (19·9°)	1·51602 (19·9°)	250·7 (19·9—20°)	506
Toluene, No. 32 (P.H.V.)	1·48724 (20°)	1·49150 (20°)	1·50271 (20°)	1·51244 (20°)	252 (20—20°)	513
Toluene, No. 33	1·48990 (20·1°)	1·49426 (20·1°)	1·50556 (20·1°)	1·51547 (20·1°)	255·7 (20·1—20·1°)	517
Xylene, No. 36	1·48800 (19·9°)	1·49216 (19·9°)	1·50290 (19·9°)	1·51234 (19·9°)	243·4 (19·9—19·9°)	495
Xylene, No. 37 (Brocades and Stheeman)	1·48857 (20°)	1·49284 (20°)	1·50385 (20°)	1·51320 (20°)	246·3 (20—20°)	500
Tetralin, No. 39	1·54438 (19·95°)	1·54926 (20°)	1·56167 (20°)	—	—	—
Decalin, No. 38	1·48272 (20°)	1·48534 (20°)	1·49243 (20°)	1·49847 (20°)	157·5 (20—20°)	324

in literature. As this cannot be expected from tetralin as a technical product, this is left out of consideration. The dispersion of the benzene does not differ much from the values published,[8] but the absolute refraction value observed is lower. Subsequently all observations were made as far as possible at 20° C., and these are given in Table II., most of the samples mentioned being new, as indicated by the numbers. The origin of the products, as far as is known, is mentioned and they were in a purer condition, such as pentane No. 40, hexane No. 41, octylene No. 43, hexadecene No. 42, and paraxylene No. 35 (products from Kahlbaum), the values of which agreed with published figures. For comparison, particulars of a sample of tetraline and of decaline are also given and the table contains data of a sample of metaxylene No. 34 (from Poulenc).

From the above it is seen that, in many cases, the absolute values of refraction give more accurate information on the purity than the dispersion. The dispersion may be specially used to identify the class of the hydrocarbon.

To prove that some of the products investigated were impure, and to learn something of the nature of the impurities, some of the hydrocarbons in Tables I. and II. have been fractionated. Hexadecene No. 42 was distilled in cathode-vacuum, using the distillation apparatus previously described.[9] Heptane from petroleum No. 1 had an initial boiling-point much below 95° C., only a small percentage boiling higher (Table III.). The product No. 1 probably contained a small percentage of normal heptane

TABLE III.

Distillation of Heptane from Petroleum, No. 1 (*Schuckardt*).

Amount used, 42·47 grams.

	Grams.
Distillate below 95° C.	38·8
Residue above 95° C.	2·63
	41·43
Loss	± 1

	Distillate.	Residue.
n_C	1·39581 (19·9°)	1·40482 (19·9°)
n_D	1·39795 (19·9°)	1·40698 (19·9°)
n_F	1·40282 (20°)	1·41213 (20°)
n_G^1 (ext)	1·40696 (19·9°)	1·41651 (19·9°)
$(n_G^1 - n_C)\ 10^4$	111·5 (19·9—19·9°)	116·9 (19·9—19·9°)

[8] Landolt-Börnstein II., p. 971.

[9] H. I. Waterman and H. J. Rijks, "Distillation of Cocoanut Oil at very Low Pressure," *Z. deut. Oel-Fett. Ind.*, 1926, **46**, 1177.

and many low boiling hydrocarbons, and this presumption was in accordance with the results obtained in the determination of molecular weight (Victor Meyer method). Mr. Doting, *e.g.*, found the molecular weight of the original sample (No. 1) and its two fractions to be as follows:—

	Original sample.	Distillate below 95° C.	Residue above 95° C.	
	91·5	94·2	102·3	98·3
	96·0	94·6	104·0	99·2
	94·1	94·5	102·3	102·0
	92·5	94·6	101·9	98·3
	92·7	—	—	—
Average	93·4	94·5	102·6	99·5
Bath temperature during the experiment	131°	131°	131°	131°

From this it is seen that only the residue has a molecular weight which approaches the theoretical value of heptane (100). The impurity of the samples of octane from petroleum Nos. 17 and 8 was anticipated from the figures given in Table I., and was ascertained from the distillation of Sample No. 17, Table IV.

TABLE IV.

Distillation of Octane from Petroleum, No. 17 (Schuckardt).

Amount used, 20·67 g. Barometer, 756 m.M. at 17° C. First drop at 105° C

	g.
Distillate, 105—124° C. (I.)	2·61
„ 124—126·5° C. (II.)	2·36
„ 126·5—129° C. (III.)	2·51
„ 129—137° C. (IV.)	7·44
Residue above 137° C. (pale yellow)	5·43
Loss	0·32
	20·67

	Octane No. 17.	I.	II.	III.	IV.	Residue.
n	1·42044 (11·2°)	1·41653 (9·9°)	1·41693 (9·65°)	1·41834 (9·5°)	1·41974 (9·05°)	1·42658 (8·6°)
n_D	1·42280 (11·5°)	1·41870 (10·0°)	1·41960 (9·55°)	1·42040 (9·41°)	1·42290 (8·7°)	1·42920 (8·7°)
n_F	1·42823 (11·5°)	1·42440 (9·85°)	1·42498 (9·65°)	1·42616 (9·5°)	1·42823 (8·9°)	1·43486 (8·6°)
n_G^1 (aa) ..	1·43307 (11·55°)	1·42940 (9·6°)	1·42989 (9·6°)	1·43093 (9·55°)	1·43327 (8·75°)	1·43968 (8·6°)
$(n_G^1 - n)\ 10^4$	126·3 (11·55-11·2°)	128·7 (9·6-9·9°)	129·6 (9·6-9·65°)	125·9 (9·55-9·5°)	135·3 (8·75-9·05°)	131·0 (8·6-8·6°)

It is strange that the dispersion ($n_\alpha^1 - n_c$) of almost all the distillates is higher than the dispersion of the original product, and from this it may be concluded that the fractional distillation has not succeeded in separating the low dispersion products from those of very high dispersion.

Not only the long boiling range, but also the high percentage of the portion boiling over 129° C., indicated the probable presence of higher hydrocarbons in octane No. 17, and this was in accordance with the molecular weight determinations carried out by Mr. Doting by the Victor Meyer method, as follows (octane No. 16 had a theoretical molecular weight of 114) :—

	Octane No. 16.	Octane No. 8.	Octane No. 17.
	114·9	116	117·6
	115·2	115·8	119
	113·5	116·3	118·2
	113	—	118·2
	115	—	—
Average	114·3	116	118·2
Bath temperature during the experiment ..	181°	181°	181°

Hexane No. 41 (see also Table II.) gave nearly the correct molecular weight (bath temperature, 131°), 83·3, 85·4, 89·7, 90·6, average 87·2, the theoretical value being 86.

Caprylene No. 43 (symm. methyl-n amyl-ethylene) proved to be a mixture, distillation giving a fraction boiling between 122·8° to 124° C. (Table V.) which had a higher bromine number (140·8) differing less from the theoretical value of 143. Mr. Doting's molecular weight determination (Victor Meyer method) gave the theoretical value : 113·3, 113·7, 112·7, 111·0, 111·0, 112·0 (bath temperature, 181°), average 112·3 (theoretical, 112).

TABLE V.

Distillation of Caprylene, symm. methyl-n. amyl-ethylene, No. 43 (Kahlbaum, new sample).

Amount used, 19.12 g.

	g.
Distillate, 122·8—124° C. (I.)	2·51
„ 124—125° C. (II.)	5·17
„ 125—127° C. (III.)	4·98
Residue above 127° C.	5·37
Loss	1·09
	19·12

	Caprylene No. 43.	I.	II.	III.	Residue.
n_C	1·41110 (20·2°)	1·41040 (20·6°)	1·41050 (20·85°)	1·41141 (19·3°)	1·41221 (19·4°)
n_D	1·41361 (20·2°)	1·41292 (20·5°)	1·41292 (21°)	1·41401 (19·4°)	1·41481 (19·4°)
n_F	1·41981 (20·2°)	1·41902 (20·5°)	1·41902 (21°)	1·41991 (19·3°)	1·42078 (19·4°)
n^{a1} (aa) ..	1·42484 (20·15°)	1·42403 (20·6°)	1·42403 (20·9°)	1·42489 (19·3°)	1·42575 (19·4°)
$(n_c{}^1-n_c)\,10^4$	137·4 (20·15-20·2°)	136·3 (20·6-20·6°)	135·3 (20·9-20·85°)	134·8 (19·3-19·3°)	135·4 (19·4-19·4°)
Bromine No. (McIlhiney)	138·6; 138·9	140·8	138·1	139·1	136·3

The distillations of cyclohexene No. 5 (Table VI.) and paramethylcyclohexene No. 4 (Table VII.), particularly the latter, indicated contamination with aromatic substances (higher dispersion, lower bromine number). Simple fractionation at once caused an important purification, though the theoretical bromine number of paramethylcyclohexene was still considerably higher than that as determined. With the cyclohexene there was a shortage of about 5 per cent. by weight only, compared with the theoretical value. For the cyclohexene fraction 82·2—83·4° C., the theoretical molecular weight was found by Mr. Doting, the value of the original sample being too high, as follows :—

	Cyclohexene No. 5.	Fraction 82·2—83·4° C
	87·5	82·5
	86·5	83·5
	88	81·8
	86	82·6
Average	87	82·6 (theoretical, 82)
Bath temperature during the experiment	131°	131°

TABLE VI.

Distillation of Cyclohexene No. 5 (Poulenc).

Amount used, 38.46 g.

	g.
Distillate, 82·2—83·4° C. (I.)	3·24
„ 83·4—85° C. (II.)	7·42
„ 85—89·4° C. (III.)	12·85
Residue above 89·4° C.	14·29
Loss	0·66
	38·46

	Cyclohexene No. 5.	I.	II.	III.	Residue.
.. ..	1·44651 (19·85°)	1·44365 (20·4°)	1·44320 (20·8°)	1·44340 (20·95°)	1·44962 (20·9°)
.. ..	1·44917 (19·95°)	1·44622 (20·5°)	1·44597 (20·9°)	1·44617 (20·9°)	1·45227 (21·1°)
.. ..	1·45600 (19·75°)	1·45302 (20·5°)	1·45272 (20·7°)	1·45292 (20·9°)	1·45919 (21·05°)
(as) ..	1·46165 (19·7°)	1·45862 (20·4°)	1·45834 (20·8°)	1·45854 (20·9°)	1·46486 (21·1°)
$-n_c) 10^4$	151·4 (19·7-19·85°)	149·7 (20·4-20·4°)	151·4 (20·8-20·8°)	151·0 (20·9-20·95°)	152·4 (21·1-20·9°)
omine No. (McIlhiney)	184·0; 183·4	190·4	189·9	189·1	176·0

TABLE VII.

Distillation of Paramethylcyclohexene No. 4 (Poulenc).

Amount used, 21·85 g.

	g.
Distillate, 96—103° C. (I.)	1·95
,, 103—107° C. (II.)	7·57
,, 107—124° C. (III.)	6·05
Residue above 124° C. (pale yellow)	5·65
Loss	0·63
	21·85

	Paramethyl-cyclohexene No. 4.	I.	II.	III.	Residue.
.. ..	1·44691 (21·7°)	1·43706 (21·3°)	1·43686 (22·3°)	1·43827 (22·7°)	1·47130 (21·1°)
.. ..	1·44967 (21·5°)	1·43944 (21·7°)	1·43944 (22·4°)	1·44085 (22·7°)	1·47432 (20·8°)
.. ..	1·45620 (21·55°)	1·44596 (21·5°)	1·44586 (22·3°)	1·44735 (22·65°)	1·48114 (21°)
(as) ..	1·46170 (21·55°)	1·45127 (21·45°)	1·45127 (22·3°)	1·45274 (22·6°)	1·48687 (21·2°)
$-n_c) 10^4$	147·9 (21·55-21·7°)	142·1 (21·45-21·3°)	144·1 (22·3-22·3°)	144·7 (22·6-22·7°)	155·7 (21·2°-21·1)
omine No. (McIlhiney)	129·6	140·5; 140·9	141·2; 141·0	141·4	97·5

The distillation of hexadecene No. 42 (Table VIII.) and the investigation of the distillates proved that this product had been purified. The bromine value (67·05) of the fraction 70—80° C. only differs by four units from the theoretical value (71·4), although the refraction is almost equal to that of the original substance.

TABLE VIII.

High-vacuum Distillate of Hexadecene No. 42.

Distillate, 38·8—41·2° C. (I.)	.. ..	9·1	per cent. by weight.
,, 41·2—70° C. (II.)	.. ..	15·7	,, ,,
,, 70—80° C. (III.)	.. ..	44·1	,, ,,
Residue above 80° C.	.. .. ..	28·5	,, ,,
Loss	.. ..	2·6	,, ,,
		100·0	,, ,,

	Hexadecene No. 42.	I.	II.	III.	Residue.
n_C	1·43897 (20·15°)	1·43711 (20·3°)	1·43817 (20·3°)	1·43867 (20·3°)	1·44013 (20·3°)
n_D	1·44135 (20·25°)	1·43954 (20·3°)	1·44060 (20·3°)	1·44110 (20·3°)	1·44250 (20·3°)
n_F	1·44725 (20·1°)	1·44542 (20·3°)	1·44651 (20·3°)	1·44705 (20·3°)	1·44850 (20·3°)
n_o^1 ($_{434}$) ..	1·45225 (20·1°)	1·45034 (20·3°)	1·45146 (20·3°)	1·45200 (20·3°)	1·45342 (20·3°)
$(n_o^1 - n_o)\ 10^4$	132·8 (20·1-20·15°)	132·3 (20·3-20·3°)	132·9 (20·3-20·3°)	133·3 (20·3-20·3°)	132·9 (20·3-20·3°)
$(n_o^1 - n_c)\ 10^4$	301·0	301·0	301·6	302·0	300·3
$\frac{n_D - 1}{n_D}$ Bromine No. (McIlhiney)	64·0 ; 64·1	64·85	65·57	67·05 (Theoretical, 71·4	59·23

It is thus proved, by the method of investigation followed, that in different cases products which, in relation to their refractive indices, might be considered as pure compounds are really mixtures.

The value of the method of investigation in research on cracking and hydrogenation is proved, *e.g.*, by work carried out in the author's laboratory by Mr. J. Schotsman on vapour-phase cracking of paraffin wax. The data published on vapour-phase cracking are not very reliable and it is often not certain that the substance in question is not already wholly or partly decomposed when brought into the vapour-phase.

In this work Rangoon paraffin was distilled at about 300° C. in a vacuum (6 m.M. Hg), the vapours being conducted through an iron spiral of about 10 m. in length, heated in a graphite bath at 450° C. That the paraffin would undergo no change in distillation at about 300° C. was anticipated from earlier experiments, and was also in agreement with the properties of the distillation residues. The tube connecting the flask with the spiral was insulated with asbestos and heated by a special burner to about 300° C. to prevent any condensation of paraffin vapours. The flask was heated in a graphite bath at 300—330° C., and the spiral was also placed in a graphite bath in which two nitrogen-filled thermometers were placed at different heights. Between the spiral and the

air-cooled tube there was a water-cooled bulb which served to collect the solid product formed without danger of choking. The air-cooler was followed by an ordinary water-cooler, then a cylinder measuring glass was used and finally two spirals cooled with liquid air. The corks used for shutting-off at high temperatures were impregnated with water glass.

From 243 g. of Rangoon paraffin, 152 g. of distillate, under 450° C. in the vapour-phase, was collected in the first receiver bulb. The residue in the flask weighed 92 g., a surplus of 1 g. due to possible inaccuracy in the rough weighings. The distillate was pale yellow in colour, and the residue in the flask pale grey. If molten, the latter was pale yellow and quite clear.

As might be expected, there was practically no condensation in the spirals cooled with liquid air. The duration of the experiment was 4 hours, the time of preheating being about half-an-hour. The temperature of the graphite bath for the flask varied between 315 to 333° C., that of the isolated tube between flask and spiral from 280 to 310° C., and of the graphite bath for the spiral between about 460 to 450° C.

The molecular weight (Rast method, lowering of melting-point of camphor), the setting point (Shukoff method) and the bromine number (McIlhiney method) were determined for the raw material, the distillate and the residue, as follows :—

	Original paraffin.	Distillate.	Residue.
Molecular weight ..	383—387	386—386	412—422
Setting point	58° C.	55·2° C.	63—64° C.
Bromine No. (addition) ..	0·9	0·9—1·1	0·6

Although the higher molecular weight and setting point of the residue tended to indicate that lower fractions of the wax had been distilled, the observations do not give the impression that cracking has occurred, in spite of the high temperature (450—460° C.). This was in accordance with the refractometric observations :—

	Rangoon paraffin.	Vapour-phase distillate at 450—460° C.
n_c	1·43154 (69·4°)	1·42974 (70·1°)
n_D	1·43367 (69·4°)	1·43187 (70·1°)
n_F	1·43905 (69·3°)	1·43736 (70·15°)
$n_D^{1\ (sat)}$	1·44350 (69·4°)	1·44164 (70·3°)
$(n_D^1 - n_c)10^4$ ..	119·6 (69·4—69·4°)	119·0 (70·3—70·1°)

The dispersion of the distillate was practically the same as for the raw material.

At first it seems strange that, although the material was exposed to a temperature of 450—460° C., cracking might be neglected. From formal experiments it is known that paraffin decomposes at this temperature in a relatively short time, but these experiments are not really contradictory. The spiral had a length of 10 m. and a diameter of about 1 cm., and its content might be estimated at $(3{\cdot}14\times0{\cdot}25\times1000)$ c.c.$=(3{\cdot}14\times0{\cdot}25)$ litres$=$about 0·785 litres. The volume of 152 g. of paraffin with an average molecular weight of about 385, may be estimated at 3,000 litres in the vapour-phase, and this volume passed through the spiral in 4 hours. It can be supposed that each paraffin part remained in the spiral for x seconds: $\frac{4\times60\times60}{x4}\,0{\cdot}785=3000$, therefore the paraffin remained in the spiral for about 4 seconds only and this sufficiently explains that cracking might be neglected.

An interesting observation was made by Mr. D. van der Linden during the cracking of paraffin under the influence of $AlCl_3$. 233 g. of Rangoon paraffin with 27·5 g. of $AlCl_3$ were placed in an iron vessel fitted with a stirrer, and heated for 1 hour in an air-bath at about 250° C. (The $AlCl_3$ was prepared from aluminium and hydrochloric acid.) From this, 66 g., or 28·3 per cent., of gasoline was obtained which, after removal of the HCl by washing with water, had a specific weight of 0·6753 at 15·3 °C.; n_D, 1·383 (21° C.); I.B.P., 22° C.; F.B.P., 240° C.; residue from Engler distillation, about 3 g. of a product of a paraffin nature. The residue, which remained in the vessel, was grey and contained little carbon. After treatment with water, to remove the $AlCl_3$, and filtration, it had the appearance of ordinary paraffin.

A second similar experiment was made using 321 g. of paraffin wax and 32·5 g. of $AlCl_3$, sublimated over heated aluminium and iron. It was first heated at 200° C. for 195 min. and 44·8 g., or 13·9 per cent., of gasoline (*a*) obtained. It was then heated to 250° C. for about 90 min. and 35·9 g., or 11·2 per cent., of gasoline (*b*) obtained. The residue in the vessel was 180 g., or 56·1 per cent., of nearly pure paraffin, while an asphaltic mass was still at the bottom, together with the greater part of the aluminium. This product did not react on water and it seemed, therefore, that the $AlCl_3$ had completely worked out.

Gasoline (*a*) had a specific weight at 10° C. of 0·6651; n_D, 1·3742 (12° C.); I.B.P., 26° C.; F.B.P., 150° C.; gasoline (*b*) had a specific weight at 10° C. of 0·6840; n_D, 1·3918 (12° C.); I.B.P., 24° C.; F.B.P., 190° C. Apparently the paraffin residue in both experiments consisted of practically unchanged raw material (see Table IX.). The residues were investigated after filtration.

TABLE IX.

	Rangoon paraffin. (Previous determination.)	Residue obtained in cracking experiments with $AlCl_3$.	
		At 250° C.	At 200° C. and afterwards at 250° C.
n_C	1·43154 (69·4°)	1·43044 (70·1°)	1·43024 (69·95°)
n_D	1·43367 (69·4°)	1·43257 (70·1°)	1·43227 (69·9°)
n_F	1·43905 (69·3°)	1·43815 (70·1°)	1·43785 (69·9°)
n_G^1 (434)	1·44350 (69·4°)	1·44252 (70·05°)	1·44213 (70·3°)
$(n_G^1 - n_C)\ 10^4$ ..	119·6 (69·4—69·4°)	119·8 (70·05—70·1°)	118·9 (70·3—69·95°)
Setting point .. (Shukoff method)	58° C.	58—55° C.	57·8—57·6° C.

In the second part of this paper the comparative research of the products from the cracking and berginisation of paraffin will be dealt with chiefly.

SUMMARY.

1. A comparative summary is given of the refractive indices and dispersive power of several samples of hydrocarbons of different groups (Tables I. and II.).

2. Different examples are given to prove the use of refraction values in investigations of the purity of hydrocarbons.

3. The bromine value (McIlhiney) and the determination of molecular weight (Victor Meyer and Rast methods) also give valuable indications in many cases.

4. The method of investigation was applied to the products obtained by cracking paraffin wax in the vapour phase, this process being carried out in vacuum. Notwithstanding the high temperature used (450—460° C. for 4 hours) no cracking occurred, the reason being that the time in the cracking spiral was only 4 seconds.

5. In the cracking of paraffin wax with 10—12 per cent. of $AlCl_3$ at 250—260° C. for 1 to 4 hours, there remained a residue (about 56 per cent.) in one experiment which proved to be unchanged paraffin wax, while during the cracking 25 to 30 per cent. of gasoline had been formed from the part of the paraffin wax which was decomposed.

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Observations on the Geology of the Santa Elena Peninsula, Ecuador, South America.*

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Introduction.

The established oilfields of Peru, and the important petroleum developments in Colombia during recent years, have had the effect of focussing a considerable amount of geological attention upon the republic of Ecuador, which forms, geographically speaking, a buffer state between the two countries. International boundaries, however, have usually little in common with the boundaries of geological formations, and the greater part of the Pacific coast belt to the west of the main range of the Andes in Ecuador consists largely of Tertiary formations, certain phases of which are known to be petroliferous. Extensive tracts of country, however, are still unexplored, other regions have been condemned from the point of view of the petroleum geologist, while certain areas, such as the one about to be described, present many features of both scientific and commercial interest. What future development and exploration will reveal in Ecuador is hazardous to foretell, but the signs and portents at the present time are distinctly encouraging, and certainly justify further research.

Few localities in the world have received more study from geologists than the Santa Elena district of southern Ecuador. Beyond the classical work of Dr. Wolf[1], little, however, is found in geological literature upon this interesting part of the South American continent, but there is reason to believe that an enormous amount of data has been already acquired by geological research which, though not available for general reference, still may be traced in the archives of certain large oil corporations.

As a matter of fact, representatives from most of the more important companies of the world have visited this region during the past decade or so.

Upon reference to the map (Map 1.) it will be observed that the peninsula itself is in the form of an elongated, tongue-shaped stretch of land, terminating in the well-known landmark known as La Puntilla. The latter point forms the most westerly extension

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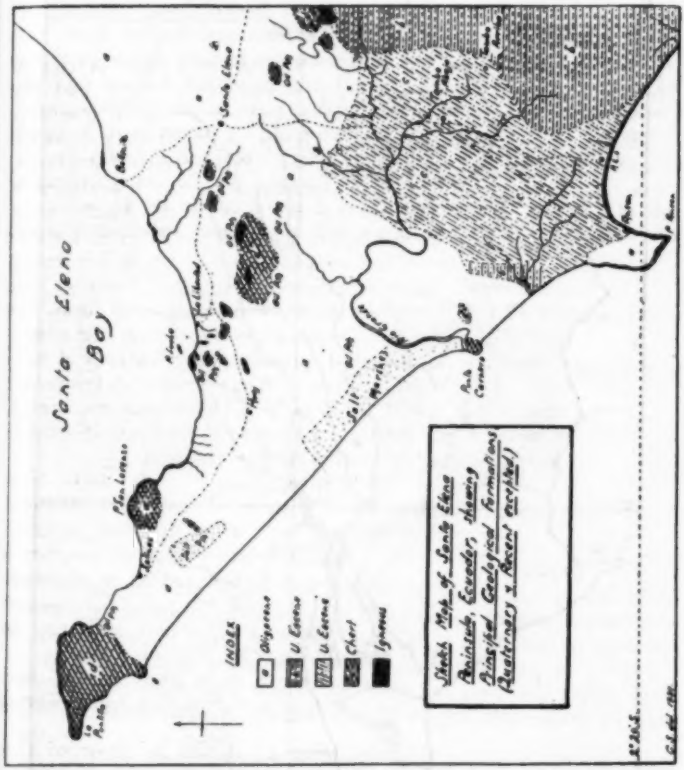
[1] T. Wolf, "Geografica y Geologia del Ecuador," 1892.

of continental Ecuador, and indeed, it is the second most westerly headland of South America.

Geographically, this extenuated peninsula forms the northern arm of the Gulf of Guayaquil and, as will be described in more detail later, owes its very existence to the fundamental nature

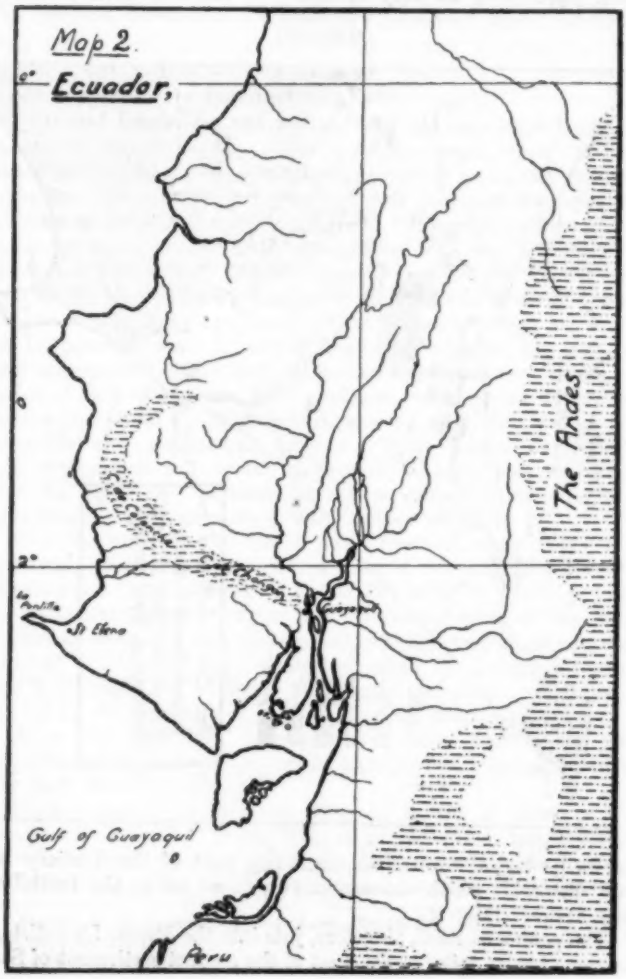
MAP 1.



of its geological formations, including part of the Tertiary belt, or "littoral," which extends eastwards as far as the foothills of the Andes. (Map 2.)

The peninsula itself, therefore, juts into the Pacific for a distance of some twelve miles to the west of the ancient settlement of Santa

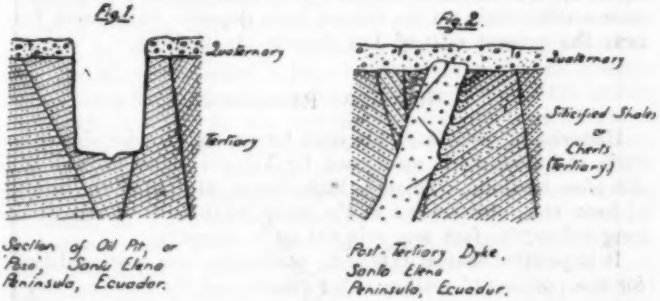
Elena. As referred to above, the strip terminates in a conspicuous flat-topped headland, the Puntilla, the latter rising to a height of nearly 250 feet above sea level. As a consequence, when observed from the sea, it appears to assume the form of an island, quite



distinct and separate from the low-lying land which connects it to the mainland. This is due to the fact that most of the land constituting the peninsular area proper is, at the present time, but a few feet above sea level, the monotonous and flat nature of the topography being relieved only by a few rounded knolls of a harder and more resistant formation.

As a matter of fact, when the geological history of this part of Ecuador (and, indeed, the same may be said of the whole of the coast belt) is appreciated, we find that at no distant epoch the area under present consideration was submerged beneath the shallow coastal waters of the Pacific. The Tertiary littoral, in effect, is slowly rising, even at the present time. In the neighbourhood of these recently uplifted shores and lagoons, the "salinas" or salt marshes are found (Map 1), whilst a few miles only to the east the crude oil, or "brea," is exploited.

In few places of the world is crude petroleum "mined" in the usually accepted meaning of the word, and these operations can



be carried out only where the petroleum is of a hard, semi-solid, or viscous nature as is the case in the brea, or natural asphaltum, found in certain parts of South America. In Ecuador, that is, in the Santa Elena peninsula, shallow, hand-dug pits, or "pozos" (Fig. 1) are made into which the thick oil gradually seeps, and finally collects into a special bucket-shaped depression at the base.

As in Peru, the petroleum workings of this type are of considerable antiquity, and although they were undoubtedly worked by the early Spanish Conquistadores, there is evidence to the belief that they were known to the pre-Colonial inhabitants of this part of the continent. Seepages, or natural exudations of crude oil, have excited human curiosity and conjecture from time immemorial, and the natives of Ecuador form no exception to this rule.

Legend and fable handed down from generation to generation of a people who could neither read nor write, gradually evolved into a form of tribal or national belief, and one of the most popular and persistent legends associated with the Santa Elena district is that which described the ancient giants who were supposed, at one time, to have lived in this part of the country. The story that there were "giants in those days" is founded upon certain elements of scientific fact in the shape of monstrous bones, tusks, and teeth which were (and occasionally still are) found in the brea pits, or natural seepages of inspissated petroleum.

Without pausing to consider the osteological differences between the skeletal remains of a primeval mastodon, and those of his alleged human contemporary, the Ecuadorean quite reasonably believes that these relics unquestionably belonged to his illustrious ancestors. Though not common, isolated bones and teeth of the mastodon (*Mastodon Andium*) can still be found in association with the ancient brea occurrences, and there is no doubt that these discoveries can be considered analogous, though on a smaller scale, to the famous bone deposits which were found near the present city of Los Angeles, in California.

Historical References.

Historically, petroleum has been known in Ecuador since about 1700, it having been mentioned by Velasco in his *History of the Kingdom of Quito*. There is little doubt, also, that the seepages of brea, etc., were known to the early inhabitants of this country long before the fact was referred to in literature.

It is possible that at this early period the brea was used largely for the purpose of sealing water vessels and for caulking dug-out canoes.

During the time of the Conquistadores, also, when the Spanish navigators frequented the western shores of this continent, the oil seepages of the Santa Elena peninsula were well known, and have been described from time to time by the various explorers of that epoch.

Fray Reginald de Lizaraga, one of the early Spanish adventurers, writing of the Ecuadorean coast, makes the following observation:—

"There is, not far from here (Punta Santa Elena) a spring, from which flows a liquid-like brea, and not in small quantities, which is utilised by vessels instead of pitch as we did with ours, because when it began leaking we put into the Bay of Caraquez, rounding Cape Pasao eight leagues beyond Manta, from where we sent the long boat with some sailors to this point for the brea, which is called "copey," and when it arrived the vessel was dis-

charged and careened and painted and caulked with the brea which had been boiled down to thicken it, so that sailing from there we navigated without so much danger."

A later writer, Zarate, has the following:—

"Near Santa Elena there are certain veins extending into the sea which contain bitumen, which looks like alquitran, and the Indians say that giants of great stature inhabited the land at this point, four times as large as a man. They do not say whence these came, but say they ate fish and were great fishermen, and went in balsas, each one in his own, because the rafts could not carry more than one. They devoured Indians thirty-two each, and went naked, and were very cruel in killing the Indians."

Long before the days of modern methods of refining, the crude oil collected from the hand-dug pits of Santa Elena was used only for the purpose of waterproofing, namely, for caulking canoes and for treating earthenware vessels or containers.

In its natural state the crude oil was too liquid for this purpose, and hence it was thickened to the right consistency by the simple process of heating, until the final tarry residue was heavy enough for use. In the early days, probably dating from pre-Spanish times, the oil was collected in large earthenware cauldrons, a series of these being built into a kind of earthwork, with a slow fire ignited in a trench beneath. In this way the more volatile constituents of the oil were driven off, and the residue used for various purposes. These ancient "pots" can still be seen in certain localities of the peninsula, and appear to have accumulated in great numbers during the course of repeated operations (Figs. 3 & 4). Evidences of this industry have been observed also in Peru, and Dr. Bosworth states[3] that in many places "pits were dug into the outcrops where natural seepages occurred. The heavy oil was skimmed, or bailed up from the pits, and was then heated in earthen cauldrons until a dense pitch or "pez" was produced. This substance was used for making an impervious lining to the large earthenware jars in which liquor was kept, and probably for various other waterproofing purposes. In the mortar used for some of the ancient buildings, pitch appears to have been one of the ingredients. It was employed also in the preservation of mummies."

During the last decade, however, a considerable amount of attention has been paid to Ecuador as a potential oil country, and, in addition to the comparatively small production derived from the local "pozo" industry, a promising yield of high grade petroleum is being developed in the more southerly part of the region under consideration.

As referred to above, the actual geographical position of Ecuador has been mainly responsible for the interest it has occasioned in the world-wide search for oil, the established oilfields, both in Colombia

FIG. 3.

ANCIENT SPANISH "POTS" USED FOR THICKENING THE CRUDE OIL (OBTAINED FROM THE PITS) BY HEATING. MANY ACCUMULATIONS OF THESE CONTAINERS ARE FOUND IN THE SANTA ELENA PENINSULA, ECUADOR.

FIG. 4.

NATURAL SEEPAGE OF "BREA," WITH PIT EXCAVATED BY THE SPANISH SETTLERS, SANTA ELENA PENINSULA, ECUADOR.

and Peru, being an additional incentive to further geological research. As a result of these primary investigations, a few test wells (and a surprising few considering the extent of the republic and the enormous acreage still awaiting development) have been completed in various parts of the coast belt, and, with the exception of the Santa Elena Peninsula, all have yielded negative results.

The present writer has visited the sites of these exploratory locations, and although the majority were probably drilled on more or less "wild-cat" grounds, it is to be regretted that more attention was not given, not only to the structural conditions governing the respective areas, but to the general appreciation and interpretation of the stratigraphical geology.

In zones of Tertiary deposition, such as are typically exemplified along the Ecuadorean littoral, too much study cannot be applied to the problems of sedimentation, a fact which, in itself, is often more important from a petroleum point of view than the generally assumed significance of suitable geological structure.

During the last few years the writer has had the opportunity of observing the practice of almost every known method for investigating the subsurface structure and the nature of the more deep-seated formations in this part of the country. These methods include systematic core drilling, preliminary shallow drilling for the purpose of determining geological structure, palæontological research, notably in connection with the foraminifera, the correlative constitution of sandstones by applying heavy liquid tests, detailed structure mapping, and underground structural work by a correlation of well samples.

Although it is recognised that all the above methods of research have their value, the results of many obtained so far in this part of the world have been disappointing. More than one geologist has thrown up his hands in despair at the impossibility of zoning by foraminifera alone; another American geologist left the country with the parting remark that the "stratigraphy was all upside down"; whilst a third, after spending more than a year diligently observing cores from certain structural test bores, came to the conclusion that most of the strata in his area were vertical.

Geographical Details.

By reference to the Map (Map 1) it will be seen that a more or less continuous line of chert outcrops (associated with igneous dykes) begins at La Puntilla and extends in a south-easterly direction for many miles. In a geographical sense, this line of chert is interesting as, while it apparently forms the "backbone" of the peninsula at the present time, it has been in the past the

principal reason why this part of the country has been preserved from the ravages of contemporary marine erosion.

There is no doubt that had the above chert masses been absent from this area, the present coastline of the country would be vastly different from the one which obtains at the present time. The

FIG. 5.

LA PUNTILLA AND SANTA ELENA BAY, VIEW WEST FROM LA LIBERTAD, ECUADOR.

FIG. 6.

LA PUNTILLA, FROM SALINAS (NOTE QUATERNARY TERRACES ON THE HEADLAND), ECUADOR.

Puntilla itself is a small tableland, and although it is always credited with an elevation of nearly 400 feet (or over) on certain Admiralty and other charts, it is actually about 250 feet above present sea-

level. Distinct terraces can be observed near the summit of the headland, these, as will be described later, being marine beaches of Quaternary age (Figs. 5 & 6). Most of the larger chert masses occurring in the peninsula have approximately the same elevation and actually (in common with a well-defined flat-topped range of hills to the north-east of Santa Elena) form erosion remnants of a continental surface, the greater part of which has since been removed by the processes of post-Quarternary erosion and denudation (Fig. 7). These local elevations are virtually the only relics of an extensive peneplain which formed, without interruption, the whole of the region under present consideration.

To the south-east of the map area the land rises gradually, and the cliffs to the south, viz., including Punta Ancon and Ancon Bay, are between 100 and 150 feet in elevation. From La Puntilla

FIG. 7.

EROSION REMNANT OF QUATERNARY TABLAZO (SKYLINE), VILLAGE AND CHURCH OF SANTA ELENA IN MIDDLE DISTANCE. ECUADOR.

to the above area, however, most of the coastline from Punta Carnero northwards is of a low-lying nature, rising but a few feet above sea level. This zone is characterised, at the present time, by extensive salt marshes which, in the neighbourhood of Salinas, are exploited commercially by the Government as the principal source of salt for the needs of the population of the Republic. There is little doubt that the whole of this low-lying area represents fundamentally the ancient estuary of the Rio Grande, the largest water course in the region. During normal seasons this river channel is dry throughout the greater part of its course, but the advent of an abnormal wet season, such as occurred in the years 1925 and 1926,

caused a rejuvenation of this river, the results of which were phenomenal.

At the present time, the estuary of the Rio Grande is in the nature of a lagoon, the mouth having been temporarily closed by the presence of a sand-bar, or storm-beach. To the east of the settlement of Ancon a certain section of the cliffs forming the coast is dissected in a remarkable manner, simulating very closely the typical "bad land" scenery which is common in other arid parts of the world. To the author's knowledge, this latter phenemenon occurs in few other parts of Ecuador, and it is a condition which has been caused entirely by the effects of a sub-tropical climate upon the geological formations occurring in this district.

Climate.

The region under present consideration is situated within two degrees south of the equator, and, upon first impressions, commensurable with the geographical situation of the country, it would be reasonable to assume that desert, or even semi-arid conditions would be found. Such, however, is not the case, and although the extensive desert of Tumbez, in Peru, lies to the immediate south of Ecuador (*i.e.*, to the south of the Gulf of Guayaquil), it is rare indeed that even semi-arid conditions prevail in any part of the country.

In the Santa Elena region very little rainfall was precipitated between the years 1918 and 1925. Vegetation was sparse, and the whole countryside presented brown and yellow stretches of sand, with occasional bare outcrops of sandstone rock. During these years, the rainy season proper (from February to April) yielded very little precipitation, and rarely exceeded five or six inches as an average rainfall. An abnormal wet season occurred, however, in 1925, followed by one of lesser intensity in 1926. During the first three months of 1925 nearly 44 inches of rain were registered, and the whole aspect of the country was changed in a very short space of time. New rivers were formed, plains and salt-marshes were converted into lakes, dry river courses became rushing torrents, and dense tropical vegetation (with grass up to four feet in height) covered the ground which, in normal years, was virtually a desert. As can be well imagined, these exceptionally heavy rains which characterised the winter of 1925 in both Ecuador and Peru, caused enormous damage to the oilfields, all development being brought to a standstill. Apart from the fact that transport was rendered useless owing to the destruction of roads and railways, many well locations were flooded and temporarily put out of action, and in the case of the Peruvian fields, one of the rivers which supplied the water for the largest camp in the district suddenly changed its course, and

the whole of the pumping plant and equipment was either destroyed, or lost, in the floods which ensued.

In Ecuador, this state of affairs put a stop to the activity of the "pozo" industry, these without exception being flooded and virtually destroyed. In the larger producing field further to the south (viz., Ancon) very little damage was done as far as actual drilling operations were concerned, but since this season one of the upper sands occurring in certain parts of the field has been found to be water-bearing. The latter feature is quite exceptional in the area under consideration, and it is undoubtedly a direct result of the subsurface drainage which was initiated during the rainy season.

Drilling operations, however, were practically suspended for four or five months, this being due principally to the cessation of transport; a considerable amount of sickness also followed, from which few members of the personnel escaped.

In normal years, the more or less "temperate" nature of the climate of the Santa Elena Peninsula can be attributed directly to the presence of the cool Humboldt current which, flowing from the south, impinges in close proximity to the southern shore, the latter forming the northern arm to the Gulf of Guayaquil.

It is possible, also, that the general topography of the Peninsula, comprising, in the main, low-lying lagoons and salt-marshes, has a certain influence upon the climate itself. The absence of either land barriers, or similar topographical eminences of magnitude, makes it possible for an uninterrupted passage of the cool south-westerly winds from the Pacific to be made across the peninsular area. As a result, little or no moisture is deposited either in the form of fine rain or mist, a climatic condition which invariably exists along the littoral of Ecuador in the vicinity of hill ranges.

Geology.

Referring to the map (Map 1) it will be seen that most of the geological formations represented in this region are of Tertiary age. These latter deposits, however, are frequently superimposed uncomformably by Quaternary sediments which are known as tablazos (tablelands) and, with the exception of the more deeply denuded areas, *e.g.* along the river valleys and near the shore-line, these Quaternary beds can be recognised easily by their characteristic "terrace" appearance in the topography.

For the most part, the Quaternary formations include hard, shelly limestones, calcareous sandstones and local conglomerates; they normally weather to a light buff colour, and form terraces of varying thickness upon the upturned beds of the underlying Tertiaries.

From their lithology and constitution it is obvious that the tablazos were deposited in a relatively shallow sea, and the different

terraces now recognised in the Santa Elena Peninsula (and indeed along the whole of the littoral of both Ecuador and Peru) are typical raised sea-floors or beaches.

At least three tablazo levels have been identified in the area under present discussion, and these are well exhibited upon the extreme tip of the peninsula, the Puntilla. The flat-topped appearance of this headland, in addition to the parallel terraces observed at different intervals, is entirely due to the action of marine erosion, which was later followed by successive stages of tectonic uplift.

With the exception of the relatively thin Quaternary deposits referred to above, the Puntilla consists primarily of cherts, altered shales and sandstones, and curiously associated igneous masses. Although little appears in literature upon this subject, it can be mentioned that both the origin and age of the Puntilla, and indeed the whole of the chert terrain of this region, has been the subject of animated geological controversy for many years.

In different reports and papers on this problem, the cherts have been referred to as Cretaceous, Tertiary, Quaternary, Recent and Igneous, and in one book on Ecuador the author records, in a very guarded manner, that the Puntilla consists of "parallel strata of clayey sandstone."

In the opinion of the present writer, however, most of the cherts and silicified shales, etc., have been derived from true Tertiary formations, these having been metamorphosed or locally changed by the proximity of igneous dykes or similar phenomena.

As will be referred to in more detail later, the Tertiary deposits found in this part of Ecuador consist principally of sandstones, shales and occasional conglomerates. Most of the sandy members of this series are lenticular in habit, and vary considerably, often within short distances, in both character and texture. In post-Tertiary times these sediments suffered intense tectonic compression, a phase of crustal movement which was no doubt accompanied by volcanic activity in the form of the intrusion of dykes or sills. As a result of this earth movement, the Tertiary beds were intensely shattered, and locally metamorphosed to such an extent that their original lithological characters were entirely changed.

These altered sediments usually present a variety of colours, grading from red to green, the latter no doubt having been caused by the separation of various secondary mineral substances as a result of the metamorphism of the rock. Many varieties are found in these altered sediments, and include normal shales, compact porcellanites, and hard siliceous cherts.

In certain of the disturbed zones, which consist principally of complex fault and crush planes, slickensiding occurs on a major

scale, this latter process having taken place along the more competent bands of altered argillaceous material. Not infrequently, a thick inspissated oil can be observed slowly exuding through the media of these joints, or structural fractures, this apparently having migrated upwards, in a local sense, from the deeper and more normal sands of the petroliferous series.

Igneous and Chert Outcrops.

Towards the south-east of the chert mass which forms the greater part of La Puntilla a shallow pit has been excavated actually in the chert rock, and into this cavity a small quantity of thick, black oil is continually exuding. As, in this immediate vicinity, there are no exposed formations of any kind which are capable of retaining oil in quantity, it can only be assumed that the oil itself has migrated upwards from some deeper source.

In places, the country rock is intricately veined by irregular nodules, or stringers, of translucent silica of a cryptocrystalline type, especially in association with the altered shales and silicified sandstones. In other localities the whole body of the rock has been transformed into a hard, siliceous mass, with included veins, or sporadic patches of completely silicified material.

In the main, however, the cherts are represented by two varieties, red and black, though other coloured forms occur grading from pale grey to pink. It has been observed that the highly coloured varieties are nearly always found where a volcanic dyke has intruded a formation of an arenaceous nature, whilst the corresponding grey, black, or cream-coloured types connote the alteration of shales, or similar deposits of a high argillaceous content. The above phenomena may be coincidental only, but the field evidence certainly seems to corroborate the respective conditions.

In common with the silicified shales, and other members of this group, the cherts are always minutely shattered, a condition which appears to have been caused by excessive shrinking subsequent to the final stabilisation of the mass.

In the Puntilla locality the altered series include many stages, and the silicified shale can be observed passing locally into the chert, the latter form usually occurring in the centre, as a nucleus of a large fragment. Towards the western extremity of the headland the main chert body is seen to be repeatedly veined by lenticular masses of translucent silica, these occurrences exhibiting a certain parallelism.

The most interesting and puzzling phenomena in connection with the petrology of the suite of formations included in La Puntilla is the presence of certain igneous rocks. In one case only, a small

true dyke, largely decomposed, is found penetrating the altered shales at a high angle. On either side of the intrusion the shales are distinctly green in colour, this probably being due to a separation of ferric compounds, as a result of the dyke contact.

As would be expected in an example of this sort, the continuous strata on either side of the intrusion are crushed and dislocated. The intrusive nature of the igneous rock admits of no equivocation and, in the opinion of the writer, it simply represents the surface offshoot of a more deeply-seated igneous mass (Fig. 8.)

Igneous rocks of a more indefinite nature are also found in the same locality, being intimately associated with certain zones of dislocation in the altered sediments. Though of rare occurrence,

FIG. 8.

IGNEOUS DYKE IN ASSOCIATION WITH CHERTS AND ALTERED SHALES. LA PUNTILLA, ECUADOR.

the igneous rocks have the megascopic appearance of coarse andesite, or diorite. They always occur as fragmental masses of small size, from a few inches to a foot or so in dimension, and all have a peculiar lenticular habit, not infrequently appearing to have been deformed by some process allied to shearing or "drag."

The occurrences themselves are firmly embedded in the chert or silicified shale phases of the parent rock, and are found invariably in defined zones which correspond in every case to lines of dislocation.

Although the following observation is put forward but tentatively, it seems possible to the writer that the igneous types occurring in the chert represent the edge, or the selvedge, of a deeper-seated igneous mass, which has been forced to the surface along a plane of dislocation, this, in itself, giving rise to the peculiar habit and disposition of the igneous inclusions.

Referring to the map, it will be seen that a definite line of igneous and chert outcrops extends from La Puntilla in a south-easterly direction for many miles, and it is of interest to observe that small oil-pits in great numbers have been excavated in the localities which are marginal to the chert and igneous masses.

This latter phenomenon has been described more fully elsewhere,[2] but it is sufficient for the present purpose to state that a sound geological connection occurs between the presence of surface oil and the above-mentioned cherts and associated igneous intrusions.

Fundamentally, the reason for this abnormal occurrence of oil-saturated zones near the outcrops of chert and igneous rock is, no doubt, the presence of channels or migratory passages through which the oil has travelled from some lower level in the series. The cherts and dykes are invariably associated with shatter-belts, and, in addition to the actual dislocation caused by the intrusion itself, the chert masses are always fractured to a considerable degree.

Further, local "pockets" occur in the stratification, into which the oil has accumulated during the course of time. A notable feature in connection with this "shallow pit" type of oil is the almost complete absence of gas. The oil itself has a lifeless appearance, it is often thick and inspissated, and oozes almost imperceptibly from the country rock, which may be either in the nature of a shale, sandstone, chert or igneous dyke.

At least one example in the Santa Elena area consists of a typical "pozo" excavated actually alongside a true dyke rock (Fig. 2). In this case, a very slight ebullition of gas was observed at the bottom of the pit, this occurrence probably being explained by the fact that the gas was issuing upwards along the contact of the dyke and the intruded sediments. Gas is rarely present in the hand-dug pits in any quantity, as it has no doubt been continually escaping from the numerous joint-planes and fissures in the formation for an indefinite period of time, there being no structural condition in the formation which would have caused its accumulation under pressure.

The natural "brea" or asphaltum seepages are found either in association with the cherts and intrusions, or in the vicinity (usually along the axis) of a highly inclined fold.

[2] G. Sheppard, "Relation of Volcanic Dykes to Oil-Bearing Formations of Southern Ecuador," *Econ. Geol.* 21, 1926.

As an illustration of the latter type, a short, but steeply pitching anticlinal fold occurs between La Libertad and the town of Santa Elena, the axis of which is probably dislocated. The "brea" exudations found in this area follow a line which corresponds closely to the axial trend of the structure, and it is extremely probable that in this case the oil has been brought to the surface in accordance with the general conditions governing the accumulation of petroleum in geological structures.

There can be little doubt that the oil found in the peninsular area of Santa Elena (*i.e.*, excluding the Ancon field further to the south) has all migrated upwards from a deeper oil-bearing horizon of the Tertiary sediments, and although there is no direct evidence for the assumption, it is probable that the oil originated in the Eocene shales and sandstones, having later migrated into the formations of the Oligocene. It is quite possible that the brea exudations occurred in pre-Quaternary times, as the later Pleistocene deposits are not infrequently saturated with inspissated petroleum, and, moreover, contain rolled fragments of Tertiary rock denuded from the post-Tertiary land surface.

The Oil Pit Zone.

As mentioned in a previous part of this paper, the disturbed petroliferous sandstones (Tertiary) of the peninsular region are superimposed unconformably by horizontal tablazo deposits. To a certain extent these latter formations have prevented a total dissipation of the crude petroleum and thus have acted, in effect, as a "cap-rock" partially sealing the oil-bearing rocks.

It is obvious that, from the very first, no scientific considerations determined the extent of the present "pozo" areas of the Santa Elena peninsula. The early inhabitants, even as now, dug their pits where obvious indications of oil were noticed upon the surface and, as will be seen by the map, these pit zones correspond closely with the occurrence of chert and igneous dyke masses.

At the present time well over two thousand pozos are in different stages of development, though the exceptionally wet winters of 1925 and 1926 destroyed many of the producing pits. An average excavation is roughly square in section (Fig. 1) each side measuring from eight to ten feet, the depth is usually about twenty feet, this being determined by local conditions. As a general rule, a thickness of three to four feet of tablazo is encountered, the latter resting upon the Tertiary formations below. Normally, the Tertiary sandstones, etc., are comparatively soft, with a characteristic greenish colour; other pits are excavated in chert and even igneous rock.

When the zone of saturation is reached, the oil gradually seeps downwards until it finally accumulates in a small bucket-like

depression which has been made for this purpose at the bottom of the pozo.

The fact that this thick oil always occurs at a relatively shallow depth appears to suggest that a concentration has taken place in the formation, a phenomenon which has probably been occasioned by local physical conditions.

There is no doubt that most of the sandstones and associated deposits found in the vicinity of the cherts and igneous rocks are slightly impregnated with oil. Indeed, it is quite possible that the dominant green colour of certain sandstones is due, in the first instance, to natural petroleum in a finely-divided state.

This oil has migrated upwards through the structural and other channels in the formation, and, as a consequence, a saturated zone

FIG. 9.

PRIMITIVE "PIPE-LINE," SANTA ELENA PENINSULA, ECUADOR. OIL IS COLLECTED FROM THE "POZOS" AND CONVEYED TO THE LOCAL REFINERY IN THE MANNER SHOWN BY THE PHOTOGRAPH.

of thick, inspissated oil has been formed near the surface, or within a few feet from the base of the Quaternary deposits. Although actual research in connection with superficial rock temperatures has not yet been carried out in the region under consideration, there is reason to believe that the zone of saturation above described (which is the one exploited by the owners of the oil-pits) has been caused entirely by capillary movement, with a consequent inspissation of the petroleum by contact with the atmospheric air contained in the upper layers of the formation.

The capillarity of rocks is always an important factor in connection with the investigation of oilsands, and it is within the bounds of possibility that in the special case described above, which is probably unique, the zone of inspissation corresponds closely with the downward penetration of the atmosphere into the partially disintegrated sandstone formations.

In certain parts of the same area deeper drilling has been carried out by small portable rigs, and although the oil is local in its distribution, and possibly occurs in pockets caused by crush zones or planes of disturbance in the rock, it is of a light green variety, and is usually accompanied by slight evidences of gas.

On the other hand, it is fundamentally the same oil which has been later inspissated either into the thick black oil collected in the pozos, or to the "brea" seepages, or workings which are of ancient date (Figs. 4 and 9.)

The Ancon Region.

The south-easterly part of the map area under present consideration consists, in the main, of Eocene rocks. The small headland of Ancon Point is a structural outlier of Oligocene sediments, being faulted down (probably in the nature of a trough-fault) from the adjacent Eocene beds. In the actual drilling area of this field neither chart nor igneous rocks are found, it occurring well to the south of the principal line of intrusions which has been referred to above extending towards the south-east from La Pùntilla. The sedimentary deposits, therefore, are but little changed, although it is known that certain sandstones, and occasional shale horizons, are highly silicified, and thus present certain difficulties in the way of drilling.

The petroliferous sandstones exposed along the cliffs of Ancon Bay have been known for many years, and it is quite possible that these manifestations of petroleum were the cause of the later interest taken in the territory, which led to further investigation and exploitation.

The Stratigraphical Succession.

The following succession has been worked out for this district :—

A. Quaternary (Tablazos—Raised sea beaches).

Shell limestones, calcareous sandstones, conglomerates, current-bedded sandstones and general beach detritus of marine origin.

1. Upper	..	250—270 ft. above present sea level.
2. Middle	..	100—150 „ „ „
3. Lower	..	20— 50 „ „ „

Unconformity.

B. TERTIARY.

Lower Oligocene—massive sandstones with thin-bedded shales; certain sandstones contain volcanic ash, carbonised wood, lignite and fossil tree trunks, etc. Gastropod zone near base; lowest formation consists of a basal breccia containing igneous boulders and decomposed Eocene shale.

Unconformity.

Upper Eocene.—1. *Seca Stage*—300 to 500 feet of light coloured shales with occasional sandstones; shales siliceous and brittle in texture. The Seca shales rest with apparently little break upon the Socorro Stage.

2. *Socorro Stage*—a considerable thickness of blue, homogeneous shales with intercalated sandstones of varying thickness. Occasional grits or fine conglomerates occur. Orbitoids, Nummulites and other foraminifera are found in certain horizons.

Cherts, various types, including translucent to black, also brecciated and "augen" forms.

C. IGNEOUS.—Andesites or diorites of post-Eocene and pre-Oligocene age.

QUATERNARY.

Few geological formations present such striking topographical characteristics as do the Quaternary tablelands known as tablazos, which cover extensive regions in both Ecuador and Peru. As a general rule, the formations are practically horizontal, resting upon primary wave-cut benches of the Tertiary, though post-Quaternary crustal warping has, in certain instances, affected this disposition to an appreciable extent.

When observed from the sea the tablazos appear as parallel terraces in the general topography, the one above the other, these representing successive uplifts of the terrain during Quaternary times. Actually, however, the tablazo surfaces, or peneplains, are dissected and denuded quite extensively, and, for the most part, form erosion remnants only. The Quaternary deposits can probably be referred to the Pleistocene, and although the different phases of this sedimentation present features of great similarity, the strata are usually loosely consolidated and rarely exceed an individual thickness of 50 feet.

In occasional instances the original tablazo phase is not greater than a development of 10 feet, a fact which clearly illustrates the comparatively short space of time which elapsed between the initial deposition of the tablazo and the later uplift of the same into dry land.

The tablazos have a lithological and faunal similarity wherever found, and they comprise principally shell limestones, calcareous sandstones and loose conglomerates, or coarse, current-bedded sandstones with thin intercalations of limey shale. They always occur unconformably upon the denuded edges of the underlying

Tertiaries, and not infrequently the contact zone of the tablazo consists exclusively of rolled or angular fragments of Tertiary rock (some of which contain brea, or inspissated petroleum) which, from their general appearance, have not been derived from any great distance. In all probability, therefore, the Quaternary beach has been accumulated *in situ* upon a shallow marine shelf consisting of Tertiary formations (Fig. 10).

From what has been ascertained in connection with the recent deposits now being formed in the shallow bays along the littoral bench of the Pacific there is reason to believe that these, upon

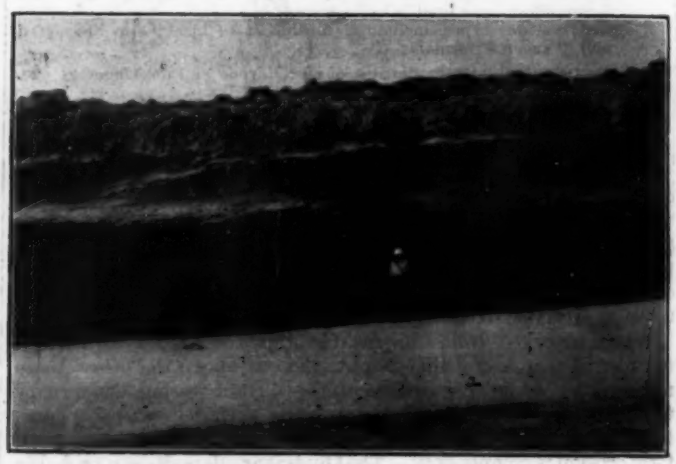


FIG. 10.

TABLAZO DEPOSITS RESTING UNCONFORMABLY UPON DISTURBED TERTIARY FORMATIONS. LA PUNTILLA, ECUADOR.

subsequent uplift, will approach very closely the appearance and constitution of the tablazos of Quaternary times. At least three tablazo episodes have been recognised in the present region, each of which represents a successive raising of the land surface during Quaternary times. Owing to the enormous amount of subærial denudation, however, which has taken place since the uplift of the oldest tablazo, the Quaternary deposits in Ecuador are preserved only as isolated outliers upon the denuded Tertiary rocks (Figs. 11, 12 & 13).

A full description of the Quaternary in Peru (with reference to those of Ecuador) has been already published[3], and the investigations of the present writer have corroborated the view that these deposits can be correlated quite satisfactorily with the tablazos of the Ecuadorean coast belt.

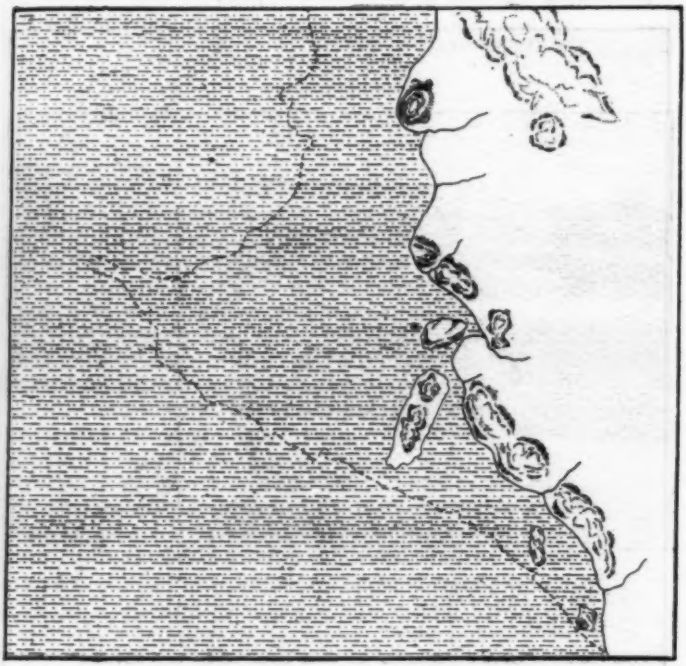


FIG. 11.

EXTENT OF FIRST INVASION OF THE QUATERNARY SEA, FOLLOWING THE SUBSIDENCE OF THE TERTIARY LAND SURFACE.

The continental area of Tertiary rocks extended much farther to the west than is indicated by the present coastline (dotted). The first (oldest) tablazo was thus left after the recession of the above sea.

[3] T. O. Bosworth, "The Geology and Palæontology of North-West Peru," 1922.

The Tertiary Formations.

The Tertiary formations, which underlie the whole of the region under present consideration, consist entirely of a thick series of areno-argillaceous sediments which are representative of both the Oligocene and Eocene groups. In a general way the deposits are curiously unfossiliferous, and beyond the fact that certain foraminifera occur (these also having a wide range throughout) and

Fig. 12.

EXTENT OF SECOND INVASION OF THE QUATERNARY SEA WITH A CONSEQUENT DEPOSITION OF THE SECOND TABLAZO.

occasional gastropods, the faunal evidence encountered in these beds is disappointing. On the other hand, certain lithological types persist which have been recognised as valuable horizon markers during the working out of the general stratigraphical succession.

On the whole, however, the sandstone members of the series are essentially shallow water, estuarine, or deltaic deposits, a fact which accounts for the presence of local conglomerates, lenticular sandstones of varying grain and texture, fine silts, current-bedded sediments, and the phenomena usually associated with lateral variation and lithological replacement.

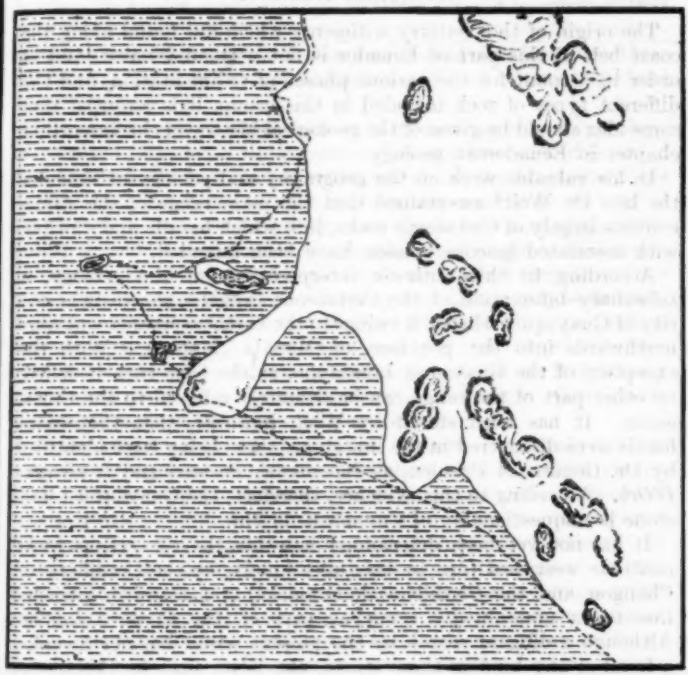


FIG. 13.

EXTENT OF THIRD INVASION OF THE QUATERNARY SEA, WITH A CONSEQUENT DEPOSITION OF THE THIRD TABLAZO.

In certain horizons of the Oligocene a denuded volcanic ash, or pumice, forms up to ninety per cent. of the rock; other beds are characterised by the presence of drift-wood, finely distributed lignitic material and other carbonaceous debris. Certain local conglomerates and breccias contain fragments of true volcanic rock,

a fact in itself which suggests the denudation of an earlier Tertiary land surface, with intruded dykes or sills.

In a general way the Eocene beds indicate a more uniform phase of deposition, as these strata consist of regular alternations of shale, sandy shale and sandstone, in addition to certain siliceous zones in the shales.

Geological History.

The origin of the Tertiary sediments which are found along the coast belt of this part of Ecuador is not without interest, and in order to account for the various phases of sedimentation, and the different types of rock included in this group, it is essential that some idea should be given of the geological history of this important chapter in Ecuadorean geology.

In his valuable work on the geography and geology of Ecuador the late Dr. Wolf[4] ascertained that the main range of the Andes consists largely of Cretaceous rocks, into which basalts and diorites, with associated igneous masses, have been intruded.

According to this author's interpretation of the geology, a subsidiary bifurcation of the Cretaceous range is shown near the city of Guayaquil, whence it swings to the north-west, and continues northwards into the province of Manabi (Map 2). With the exception of the Guayaquil Limestone, as the type rock is called, no other part of the range can be definitely referred to the Cretaceous. It has been stated by Wolf, however, that Cretaceous fossils were discovered in the limestone, these being later identified by Dr. Geinitz, of Dresden, as *Inoceramus Roemeri* and *I. plicatus D'Orb.* According to this evidence, therefore, the Guayaquil Limestone is unquestionably of Cretaceous origin.

It has not yet been determined how far the Cretaceous rocks continue westward (i.e., in the hills known as the Cordillera de Chongon and the Cordillera de Colonche), yet massive, siliceous limestones undoubtedly occur as part of the C. de Colonche. Although a diligent search by the present writer has not revealed a fossil of any kind in these strata, the latter may be Cretaceous in age, as they bear a strong lithological resemblance to the limestones found in the vicinity of Guayaquil.

The river system which now drains into the enormous estuary known as the Gulf of Guayaquil forms an episode of comparatively recent geological times, most probably dating from the close of the Quaternary. The original deltaic basin, or channel, however, into which the contributary rivers flowed from the Andes was probably in existence shortly after the beginning of the post-Cretaceous uplift.

[4] T. Wolf, "Geografica y Geologia del Ecuador," 1892.

The western flank of the Andean complex, therefore, formed the Pacific coastline of this period, the bifurcation, or lower spur referred to above constituting a group of islands.

Contemporaneously with the orogenic uplift of the Cretaceous continent, the rivers were debouching into the ocean, thus materially assisting in the accumulation of sediments now known to be Tertiary in age.

From the evidence afforded by the latter rocks it is apparent that the Cretaceous coastline was fringed by numerous shallow embayments, or estuaries, and the Tertiary sediments were formed in these depressions, being finally uplifted into the form of a continental land mass.

One of the most striking features in connection with the geology of southern Ecuador is the presence of enormous screes of denuded rock material which are found at the foot of the western slopes of the Andes. To a lesser extent, such deposits also occur near the edge of the Cordillera de Colonche; they have also been observed along the deeply eroded river valleys to the north, in the province of Manabi.

These screes are of great areal extent, and indeed they have been recognised incorporated in the Tertiary and Quaternary sediments. From the latter they have been further distributed by weathering, and transported afar by river action, and hence, at the present time, the individual boulders of the original scree material are found many miles away from their base, occurring as "foreign" boulders in almost all parts of the area under consideration.

These phenomenal accumulations of scree material indicate relatively excessive and rapid denudation of the Andean slopes, from which locality they undoubtedly originated. Abnormal precipitation of rain, and consequent intensive river action must therefore have taken place during this phase of the Tertiary sedimentation. Moreover, the coarse detritus (*e.g.*, the larger boulders) represents the margin of the Tertiary sea in a region where the larger rivers debouched, and thus dejected their load of heavier material.

The lithology of both the Oligocene and the Eocene strata indicates clearly a variation in deposition from shallow water, lagoon, estuarine and deltaic conditions. The Oligocene facies, for example, presents a diversity of features, most of which can be attributed to the effects of abnormal fluvial activity during the period of deposition. This fact, in itself, suggests a periodicity in the heavy rainfalls which were prevalent over the continental area. The upper stage of the lower Oligocene contains abundant fragments of volcanic rock, the Ancon White Sandstone (one of the subdivisions) having a high percentage of volcanic ash, of a pumice type, in its composition. From this it can be assumed that the Oligocene has probably been derived, in part, from the denudation of an earlier Eocene land

surface, certain formations of the latter having been intruded by dykes of post-Eocene and pre-Oligocene age. The contact between the Oligocene and the underlying Eocene is actually an erosion surface, and is defined by an unconformity which, in itself, indicates that a regional uplift took place resolving the Eocene into a temporary land surface.

The latter suffered considerable denudation before the succeeding subsidence was completed, this, of coure, being responsible for the invasion of the Oligocene sea.

The upper Eocene formations of this region have been divided into two stages, known as the Seca and the Socorro respectively. Owing to the complete absence of surface exposures it is almost impossible to formulate any idea regarding the nature of the lower Eocene, beyond the fact that a considerable thickness of hard and compact sandstones forms the greater part of the succession. The latter information has been derived from certain boreholes, but in no case has the base of the Eocene been reached.

The differences in lithology of the two divisions of the upper Eocene, *viz.*, the Seca Shales and the Socorro Stage, suggest a change in the conditions governing the sedimentation. The Socorro stage consists principally of shales with interbedded sandstones, whilst the overlying Seca beds include fine textured shales which are practically devoid of sandy elements and weather to a distinctive light colour.

In this region the Seca shales of the upper Eocene do not exceed a thickness of more than 500 feet. From the uniformity of their constitution, however, it is possible to deduce the fact that they were deposited in a deeper basin than the one in which the Socorro beds were laid down. This latter sea was probably of a lagoon type, and the depositional area was free from the incursion of estuarine material, as little or no sand is found in association with the shales.

The close of the Eocene period was marked by a recession of the sea from this region as a consequence of a tectonic uplift. During this interval of time both the Seca Shales and the Socorro Sandstones were folded and dislocated. The basal breccia of the lower Oligocene always contains large blocks of disintegrated Seca Shale, it being apparent, therefore, that a certain amount of erosion—most probably along a marine beach—was accomplished before the succeeding depression of the land-surface began. From the general appearance and habit of the Oligocene strata it can be inferred that current action was very prevalent, and that most of the detrital material was transported by rivers of great activity. Deltaic accumulations also are not uncommon, and large quantities of fossil wood, breccias, lignite, and seams of volcanic rock severally

indicate that the erosive power of the contributory rivers was phenomenal.

From the close of the lower Oligocene period to the beginning of the Quaternary most of the formations described above remained as a defined continental shelf, and became subject to intense denudation. The final tectonic uplift was accompanied by pronounced crustal warping and deformation of the strata, in addition to the intrusion of certain igneous dykes.

Associated with the more normal types of sedimentation included in the Tertiaries of this part of Ecuador is a distinctly unique phase which is known as the Clay Pebble Bed, and has been described.[5] The authors of this paper have suggested that the formation has been caused entirely by the overthrusting of one mass of sediment over another, and that the Clay Pebble Bed itself is the result of a great overthrust in soft sandstones and shales of Tertiary age. The present writer is not in agreement with this theory, and the field evidence (and the constitution of the deposit itself) strongly indicates that the Clay Pebble Bed of Ancon is primarily a true deposit formed, in the first place, by the denudation of an Eocene land surface, under abnormal climatic conditions. Overthrusting and shearing cannot be applied to the origin of the deposit, although these tectonic factors have undoubtedly affected the formation at a later stage of its history.

Apart from the controversial interest attached to this deposit, however, the Clay Pebble Bed has proved to be of considerable diagnostic and correlative value in certain problems connected with the underground structure of the region which is now being exploited for petroleum.

Structural Geology.

A more or less continuous zone of intense dislocation and shattering occurs along the line indicated by the outcrops of chert and igneous rock (Map 1). In many instances, it is quite impossible to form any idea of the general structure, as the respective formations, in addition to being locally altered, have been dislocated and crushed to a bewildering extent. Further to the south, however, in the Ancon region, the formations are less disturbed, though they present structural problems of considerable difficulty.

There is no doubt that a distinct monoclinal fold is present, this, in itself, having been the probable cause of the primary accumulation of oil. On the other hand, however, subsequent tectonic movement has partially obliterated this fold, which has

[5] C. Barrington Brown and R. A. Baldry, "On the Clay Pebble Bed of Ancon, Ecuador," *Q.J.G.S.*, 1925.

been thus converted into a complicated series of faulted blocks, the exact delimitations of which are difficult to ascertain. For the most part (although local minor folds occur) the whole of the Eocene strata of the Ancon area have been faulted in irregular blocks, each individual block having been displaced in relation to its neighbour. In the majority of cases the amount of "throw" is not great, but there is, in addition, good evidence of master faults, in which the lateral upthrow is considerable.

In order to visualise more clearly the present attitude of these Tertiary beds, the disposition of the blocks of strata can be compared to a sheet of plate glass which has been shattered into small parallelograms by the application of a torsional strain. If it can be imagined that each small fragment of glass is further tilted slightly, and either raised or depressed in relation to its neighbour, the illustration will serve to give some idea of what probably happened to the Tertiary formations as a result of crustal movement.

It is recognised that drilling problems peculiar to the field are present in most oil regions of the world, and it is, indeed, rare that one finds a driller who is quite satisfied with the nature of his "formations."

The sandstone horizons of the lower Tertiary beds of Ecuador are characterised by a high degree of silicification, and this, in association with the sharp, angular form of the individual sand-grains and the occasional compact lenses of quartzite pebble conglomerate, forms a medium which is by no means easy to drill either with percussion or with rotary tools.

In contrast with the Tertiary formations of Peru, where the compact, yet soft nature of the rocks admits of drilling 100 to 200 ft. per day with standard cable tools, the operations in Ecuador are considerably slower. As a general rule, however, the shallower wells to about 2,000 ft. in depth present little difficulty, and can be completed within a reasonable time, but below this horizon the compact and abrasive nature of the sandstone series appreciably retards the footage.

Another unusual phase in the sedimentation of the Eocene is what has been described as the Clay Pebble Bed of Ancon (p. 451). The matrix, or base, of this formation is a finely divided, siliceous mud into which compact clay "pebbles," occasional foreign boulders, and blocks of denuded sandstone are embedded. Whilst causing but little trouble to the percussion methods of drilling it has been proved to be a difficult medium to penetrate with the fishtail bit of the rotary equipment. This is due primarily to the abrasive nature of the formation, which dulls the edge of the bit in a very short space of time. A further troublesome factor is the "balling" effect which is caused by the clay itself upon the flanges of the

drill. The cutting action of the bit is, therefore, muffled very rapidly and, as a result, drilling is virtually stopped until the driller can clear the bit from its load. The latter process is accomplished by judicious "spudding" in conjunction with the correct fluidity of the lubricating mud.

The presence of igneous dykes with associated masses of chert has been already commented upon in the preceding pages, and the various types of rock described. It is recognised that the dyke rocks are but the differentiated offshoots of a deeper-seated igneous mass, and it is just possible that the pronounced siliceous nature of the lower Tertiary sandstones found in Ecuador has some connection with the effects of igneous intrusions. Silicification may be a direct result of pneumatolytic action, and hence it may be argued that the unusual petrological characteristics found in association with the Tertiary sediments are of secondary origin caused by the presence of the igneous dykes.

In this connection it is of interest to note that volcanic dykes are not known to occur along the "littoral" of Peru, where the sedimentary formations are homotaxially equivalent to those of Ecuador.

In this question of the comparative study of the Tertiary formations of both countries the most striking difference is the general paucity of organic remains in the Tertiaries of Ecuador and the prolific fauna which characterises the same formations further to the south, in Peru.

Almost every author on Peruvian geology has commented, not only upon the numerous genera and species which have made the zoning of the formations in Peru possible, but also upon the vast numbers of fossils which are found. Certain horizons consist almost entirely of the fossil casts of certain gastropoda, and it is an exception to the rule to find a stage or a sub-stage entirely unfossiliferous.

Excluding certain foraminifera, however, and occasional gastropods of a Turritella type (usually found in a fragmental condition), the Tertiary beds of the region under present consideration are remarkably unfossiliferous. In the Oligocene, however, fossil wood, both of the siliceous and carbonised forms, is found abundantly, but invariably in a broken state. With the exception of certain fossil fruits, and a local, thin horizon of gastropods (*Hemisinus*) little else is found of an organic nature.

How is it possible, therefore, to account for this great difference in the faunal content of the Tertiary beds of both countries, which are stratigraphically the same? The following reasons can be tentatively put forward. In the first place, there is reason to believe that certain of the Tertiary formations of Ecuador (with

the exception of the Miocene) were deposited under deeper water conditions than obtained further to the south. This, in itself, may account for the absence of certain gastropod forms which were essentially inhabitants of a shallow, littoral shelf.

The prevalence of mud-laden lagoons and coastal bays, the sediments of which became later consolidated into certain phases of the Tertiary, would undoubtedly retard the propagation of many forms of life, and hence would, in a minor way, account for the present unfossiliferous condition of certain horizons.

Another factor which must be taken into consideration is the possibility of contemporaneous volcanic activity in connection with the sedimentation of the Tertiary beds in this coastal zone of Ecuador. Although the problem is still under investigation,

FIG. 14.

SELENITE VEINS AND EFFLORESCENCES OF SULPHUR, EOCENE SHALES, S. ECUADOR.

it has been established that possibly two phases of volcanic activity took place in the region under present consideration, the first being post-Eocene and pre-Oligocene, and the second post-Miocene and pre-Quaternary. Certain of the basal Oligocene strata contain volcanic blocks and boulders in considerable quantity, and from their appearance they have not been derived from any great distance. Megascopically, these occurrences resemble the volcanic dykes and sills which have intruded the Eocene formations.

In this connection it may be noted that a well-known horizon of the Oligocene in this neighbourhood contains almost 90 per cent. of denuded, or redistributed volcanic glass, or ash of a pumice type.

It is possible, therefore, that this phenomenon, in itself, may be sufficient to account for the lack of faunal evidence in the contemporaneous sediments.

On the other hand, the presence of a current of low-temperature water would have the sudden effect of destroying many forms of crustacean and gastropodal life which had been previously accustomed to tropical waters.

Had this phenomenon occurred, however, its effect would have been local only, as it only influenced, in a negative way, the distribution of life in the region now recognised as the coast belt of Ecuador.

Following the close of the Tertiary period the whole terrain was uplifted and became a continental shelf, which region had much greater westerly extension than obtains at the present time.

Soundings taken by the British Admiralty, with subsequent corrections by other authorities, indicate on the charts that the submarine coastal shelf of Ecuador shallows very gradually to about five miles west of the mainland. Beyond this the shelf terminates abruptly, deep water being registered to about 1,800 fathoms. (See Charts Nos. 1123 and 1177, published by the Hydrographic Office of the United States Navy.)

At the present time the geological evidence appears to suggest that an erosion interval of great length occurred before the regional subsidence took place which allowed the deposition of the first tablazo phase upon the eroded land surface of the Tertiary. Curiously enough, and in great contrast to the faunal conditions which prevailed during the sedimentation of the Tertiary formations, the Quaternary tablazos are crowded with all kinds, both genera and species, of many molluscs, gastropods, corals, and other forms of life which undoubtedly indicate a favourable habitat under tropical conditions.

In both Ecuador and Peru, a prolific fauna is found in the Quaternary beds. This, in itself, indicates that the oceanic waters of the Quaternary formed a suitable environment for these life forms, a condition which did not obtain during the deposition of the Tertiaries in Ecuador.

It is convenient, at this stage, to compare the nature of the geological structures which are found in association with the Tertiary sediments of both Ecuador and Peru. In Peru there is a general absence of anticlinal folds (*sensu stricto*), and most of the "littoral" consists of an intricate and complicated system of faulted

blocks, which structural units have been proved valuable as indices to petroleum development.

Little water occurs in the formations, a factor which is distinctly important from a drilling point of view.

Along the Ecuadorean coast belt the structural conditions are similar to those outlined above, with the exception that certain local folds occur which are partially disguised by later step-faulting and possible overthrusting.

There are zones, however, in the Santa Elena region, which are virtually shatter-belts, and in such localities the formations are disturbed and dislocated in a bewildering manner, so much so that it is quite impossible to obtain an accurate idea of the structure by the process of field mapping. Apparently, the tectonic forces which have affected the disposition of the stratified deposits in this region have been resolved in a periodic manner, as it has been observed that zones of intense dislocation are alternated by areas of relatively gentle flexure and, at the same time, there is a distinct parallelism in the structural units. Most of the tectonic lines in Southern Ecuador have a general direction, N.N.W.—S.S.E. Although in this region shatter-belts and minor folds are found, the dominant structure is of a "faulted-block" type and, in the majority of cases, the amount of "throw" or relative dislocation is not great.

Distribution of Petroleum.

In Southern Ecuador the principal oil-producing sands are found in the upper Eocene, and it is believed that the oil itself is indigenous to the formation in which it now occurs. So far, however, the base of the Eocene has not been reached by the drill, but from the nature of the deeper formations (never exposed superficially but judged only from the well samples) and the habit of certain oil sands at these levels, it must be assumed that the oil has its origin in the shales which make up the greater part of these Tertiary sediments.

Seepages of petroleum, and productive horizons, range from the upper Eocene to the Oligocene, and although it is quite possible that certain shale deposits of the Oligocene may have been the cause of the presence of oil in these beds, it is the opinion of the writer that the majority of these oil occurrences which are found higher than the Eocene have been occasioned entirely by upward migration.

It is interesting to note that the only formation in the district which contains fossil wood in any quantity, viz., the Oligocene, is virtually non-petroliferous. Migratory oil, however, is found amongst the Oligocene formations of the peninsular area proper of Santa Elena, and is fairly widely distributed.

In 1922 a well-known American oil company tested a large area considerably to the east of the one under present consideration, and drilled a well to a depth of over 6,000 feet. The results were entirely negative, and the operations were consequently abandoned. The attempt was certainly justified upon geological grounds, as the test well was located near the crest of an extensive and low-dipping anticlinal fold consisting superficially of Miocene formations. Although no information has been published regarding the nature of the strata penetrated during this test, there is reason to believe that the whole of the series were of Miocene age throughout.

The result of this enterprise appears to prove that the Miocene of southern Ecuador is not oil-bearing, a condition which is different in the Miocene of Peru, *e.g.*, at Zorritos.

The Tertiary sandstones found in the oilfields of Ecuador are essentially of a compacted type, and are invariably alternated by shales of considerable thickness. For the most part, these shales are dark coloured and contain sulphide of iron in small quantity. Weathered outcrops or cliff sections are often distinctly coloured by exflorescences of finely-divided sulphur, and, in addition, selenite plates, or veins, are commonly found (Fig. 14).

It has been suggested that the above minerals indicate a former existence of organic matter which was incorporated with the primary shale substance before the latter became consolidated into a stratified rock.

In certain parts of the Ancon field the intimate association between shale horizons and oil-bearing sandstones is clearly demonstrated, and almost every sandy layer intercalated amongst the shales is petroliferous to a greater or less degree. In one case, a fairly close-textured sandstone, not more than a foot or so in thickness, has been known to yield a considerable quantity of oil in a relatively short time.

In this particular instance the sandstone is lenticular in habit, and also occurs in thin laminæ intimately interstratified with the blue shales. Within certain limits every sandstone layer is impregnated with gaseous petroleum, and hence it seems impossible to suggest that the oil could have originated in any medium other than the contiguous shales.

In this field the drilling has proved the existence of certain well-defined producing horizons; yet, on the other hand, it must be recognised that a considerable amount of oil is collected in the wells as the result of the many smaller sands which are penetrated by the drill. Each of these has its own oil-content and gas pressure and, in many cases, the cumulative result of many "shows" is sufficient to justify the well being put on production. In certain cases, although the well yields a satisfactory amount of petroleum, the

gas pressure is hardly great enough to cause the well to flow by intermittent heads. Swabbing is applied as a consequence, in order to assist the flow.

Other wells, however, flow more or less continuously for the whole twenty-four hours, the oil being finely-divided, or reduced to a spray, by reason of the high gas pressure.

Indications of Petroleum.

In the area under special consideration, viz., the Santa Elena Peninsula, the natural occurrences, or "indications" of petroleum are numerous and widespread.

Towards the north of the map area, seepages of thick, inspissated brea (which include the "bone-beds," and the localities worked by the early Spanish settlers) are common, and, as has been commented upon in an earlier part of this paper, are usually found in the neighbourhood of chert outcrops and igneous intrusions.

To the south—that is, in the vicinity of the Ancon field—the cliff sections frequently present excellent examples of exposed oilsands, these being found also along certain of the river valleys inland. In these cases the oil itself is of a dark colour, having been naturally inspissated by reason of its exposure to the atmosphere. This inspissation has been caused primarily by the action of the sun, which has caused the accumulation of oil on the sandstone surfaces through the medium of the superficial capillaries of the rock. The volatile constituents are rapidly dissipated and, as a result, a dark brown stain is left upon the sandstone ledges, being quite conspicuous amongst the blue or grey shales. Although these natural seepages are fairly common in the vicinity of Ancon Bay, they are more rarely found considerably to the north, and to the south-east, of the region under discussion, and bear the same characteristics as those referred to above.

In semi-arid countries gas seepages are difficult to detect yet it has been ascertained during the wet season of the year, that, in this present area, gas is continually escaping into the atmosphere through the media of cracks or joints in the sandstone rocks.

"Puff" sand, which has been quoted by several authors as an indication of gas, is also of local occurrence, and can be observed especially well along dry sandy valleys, or in the desiccated, superficial deposits of dry lagoons.

Although the agency of constantly escaping gas working upwards through the loose sand has been ascribed to the formation of the finely comminuted or "puff" sand, it is considered by the present writer that this peculiar condition has been occasioned primarily

by local chemical action. The "puff" sands, which are usually found in the "salinas" or salt marshes, are possibly the result of hygroscopic degradation due to the presence of sodium chloride and other salts in the sand itself. Repeated segregations of moisture from the atmosphere, alternated by periods of rapid evaporation would cause, in a very short space of time, a comminuted sand very similar, or identical, to the material which was supposed to have been caused entirely by emanations of natural gas.

Though of rare occurrence, mud springs, or mud volcanoes, are found in southern Ecuador, though not strictly in the Santa Elena region. As a general rule, a mud volcano is an undoubted indication of the presence of gas, and if this phenomenon is accompanied by oil it can be assumed that the latter has migrated from some deeper source along a fissure, or joint, which has been the primary cause of the formation of the "volcano."

The hot springs, and the mud volcano of San Vicente (to the south-east of the town of Santa Elena) is a case in point. The "volcancito," as it is called, is of a low, conical form about thirty feet in diameter and six feet high. It consists for the most part of heavy mud, the superficial layers of which have been indurated by the sun. Towards the centre of the cone, water and gas, with a little oil, are continually exuding, and hence the continuous emission of the gas, in the form of viscous bubbles, causes the formation of thick mud which is streaked with crude petroleum.

Periodically, the ebullition of the gas causes an overflow of the mud which occupies the crater, and thus the formation of the present cone of the "volcano" has been defined.

A short distance away, that is towards the centre of the trench-shaped valley of the Rio Grande, a flow of warm water (from 32 to 40 degrees C.) seeps upwards from the rocks in considerable quantity. These permanent hot springs are considered to be of great medicinal value by the inhabitants of the country. The actual springs are apparently found along a line (in addition to the mud volcano) which most probably corresponds to a fault occurring along the crest of a dislocated anticlinal fold. In this locality the sandstones are probably of Oligocene age and they are locally inclined at a high angle.

An interesting feature of this district is the presence of smaller, subsidiary cones, perfect in shape, which range in height from three to ten inches. The crater of each of the latter is usually filled with mud through which gas bubbles burst intermittently. This gas is inflammable. The water of the above springs contains chloride of sodium, potassium, etc., in addition to certain bromides and iodides.

A similar mud volcano of less spectacular interest occurs near the village of San Jose de Amen, midway between Santa Elena and Guayaquil, and this undoubtedly indicates a continuous gas seepage. The gas apparently issues from some fault in the Miocene, which formations have an extensive areal distribution in this part of the country.

Along the coast to the south-east of Ancon distinct seepages of oil can be observed occasionally in the sea, usually in the breaker zone near the shoreline. This oil has a yellow appearance and seems to occur in patches on the disturbed water. In these places the spume, or foam, which is carried inshore by the wind, is frequently oil-stained, a fact which can be readily demonstrated by squeezing the foam into a white handkerchief.

This phenomenon of oil upon the sea indicates the presence of exposed oilsands below low water mark, and the occurrences appear to be coincident with fault planes which are noticeable in the adjoining cliffs.

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

THE FOURTH GENERAL MEETING of the RUMANIAN BRANCH of the Institution of Petroleum Technologists was held at the Industrial International Club, Ploești, on Friday evening, January 28, 1927, Mr. A. Frank Dabell, M.I.Mech.E., Chairman, occupying the Chair.

The following Paper was read :—

The Wire Rope.

By PERCY R. CLARK (Associate Member).

The author, having touched on the scope and history of the wire rope, presented a diagram giving the general classification of the different types of wire rope generally used, with the following explanation :—

The normal construction for a rope is six or more strands around a fibre core, each strand, if of simple construction, consisting of 7, 12, 19, 24, 27, 30, 37, 48, 61 or 91 wires. Strands with 24 and 30 wires each have another fibre core, which also might be the case with the 12-wire strand. If of compound construction, the strand is made of wires of different gauges. Of the sub-divisions of the normal construction, the ordinary (or cross) lay, in which the wires are twisted in one direction and the strands in the other, is almost exclusively used in the petroleum industry, whilst in the mining industry the Lang's lay (in which the wires and strands are twisted in one and the same direction) holds sway. The reason is not far to seek. Two of the chief causes of rope destruction are :—

(*a*) Abrasion, and

(*b*) Flexation.

The latter word the author gave as one of his own coining, intended to mean the state of being subjected to flexions.

A glance at the Lang's lay rope will show that it has the following advantages :—

1. The particular disposition of the wire gives a considerable surface for resistance to abrasion, whereas with the ordinary (or cross) lay rope there is only the peak of the circumference of

the strand that is subjected to wear. Obviously, the greater the distribution of the wear the less thickness will be worn through in a given time. Hence longer life to the rope.

2. The Lang's lay rope, not having the individual wires parallel with the rope itself, but at an angle which will vary as a result of the combined lays of the rope and strand, presents a greater resistance to bends over the pulleys.

The standard flexion test for wires up to about 2½ mm. is to grip the wire vertically between the two cylindrically-shaped pieces of steel with a radius of 5 mm., the wire being held at right angles to the vice. The piece being subjected to test is then bent backwards and forwards over an arc of about 180°. Now, a good quality of 18-gauge steel wire is not expected to stand more than twenty-two such bends. It will thus be appreciated to what extent the life of the rope is shortened by continually bending over pulleys. The wires forming a Lang's lay rope are not at right angles to the axis of the pulley, but at an angle which, as already explained, varies with the lay of the strand and rope. The nearer we get the wire in alignment with the axis of the pulley or cylinders of the testing machine, the more bends it will stand—in other words, the more it just revolves and the less it is actually subjected to flexion. That can be proved in a few minutes on any flexion testing machine. To go to the extreme, if the wire is placed absolutely horizontally, *i.e.*, quite parallel with the cylinders of the testing machine or pulley axis, one can go on turning it backwards and forwards almost *ad infinitum*; in short, it is just revolving on its own axis and not bending.

It will thus be seen that the Lang's lay rope by its construction is much better fitted than the ordinary lay rope to withstand two of the main causes of wire-rope destruction. But the Lang's lay rope, having its wires and strands twisted in the same direction, has a greater tendency to untwist than the ordinary lay rope, in which the ropes and strands are twisted in opposite directions, the natural recoil of one thus tending to counteract the recoil of the other. For this reason the Lang's lay rope can only be used where both ends are fixed. This condition exists for the more important ropes employed in a mine, *e.g.*, the haulage rope, which is sometimes endless and sometimes has one end fixed to the drum and the other to the truck, and the winding rope, which is attached at one end to the drum and at the other to the cage held in position by guide ropes. In the petroleum industry, on the other hand, one end of the rope generally hangs loose, always when baling and sometimes when drilling. Hence the Lang's lay rope has more general application in the coal and iron mines and the ordinary lay in the petroleum industry.

The cable-laid rope is really a number of flexible ropes twisted around another fibre core. Hrabak, an engineer who published a very good work in many respects on the wire rope some twenty-three years ago, asserted that the strain on a rope in passing around a pulley or the like varies inversely with the complexity of the stranding. For example, taking the strain on a single wire as unity, he gives the value in the case of a strand as 0·6; for a rope with two stages of twisting, *i.e.*, the normal rope, $0{\cdot}6^2=0{\cdot}36$, and for one with three stages of twisting, *i.e.*, the cable-laid rope, $0{\cdot}6^3=0{\cdot}216$. He considered that the cable lay imparted high flexibility, the strain set up in bending being correspondingly low, and this view was at one time generally accepted in rope-making circles and is to-day by many users of wire ropes. However, it has since been shown that considerable stresses are set up in the manufacture of the rope, which are increased by internal friction and wear produced by the mutual pressure of the wires when the rope is bent round a pulley. These factors combined with (1) the effects of the pressure of the rope on the pulley and (2) of rope *slip*, tend to lessen the difference between the strain on single wires and stranded ropes to an extent which increases with the complexity of the stranding. This has been furthermore confirmed by a series of experiments carried out by Professor Dr. Woernle, which gave the following approximate ratios of length of service between the three kinds of ropes:—

> If the average life of the Lang's lay rope be represented as 100, then the average life of the ordinary lay rope will equal 26, and of the cable-laid rope 14.

Next we come to the concentric strand rope. This is a type of rope which has not met with any significant success; the objection to this type is, that in the making of the rope one has to put pressure on the outer strands which have as their bed similar wire strands. This is a severe strain on the wire. With the normal rope the strands lie in a soft fibre bed. Out of the concentric strand rope arose the idea of the nontwist or nuflex rope. Theoretically, this rope was to be adopted for all work where one end of the rope hung loose, and, had it fulfilled what was promised for it, the nuflex rope would have superseded all others for most oilfield work. The principle of the nontwist rope was that the inner strands were to be twisted in one direction and the outer strands in the other direction, the recoil or untwisting effect of one lot of strands thus counteracting the recoil of the other layer. However, in practice the unforeseen occurred—when the rope happened to be subjected to a particular twisting pressure in the direction in which the outer layer of strands was twisted, *i.e.*, to have the effect of still further tightening the twist of the outer

layers, the twist of the inner strands was loosened, *i.e.*, an unwinding effect was given to them which tended to open out the strands. The results were a bulging out of the outer layers in parts, the rope thrown out of alignment, and a quick death.

The flattened strand is one of the most modern ropes and it is fancied by certain mining engineers. It has a shaped centre (generally flat or triangular) covered by ordinary round wires. The nature of the centre gives a flat surface on the outer side of each strand, which thus gives some of the advantages of the Lang's lay rope, *viz.*, a larger surface of wire to withstand the effect of abrasion. But as regards the other quality of the Lang's lay rope, *viz.*, resistance to flexions, the position is reversed; in the making of the strand, the wires are bent under considerable pressure around the sharp edges of the centre, and in this position they remain subject to the continual bends attendant on the working of a rope. Obviously the individual wires will break more quickly, and at the point they are bent round the sharp edges of the core.

Arising out of these two ropes we have a combined nontwist and flattened strand rope.

The author had not seen a rope of this type at work but had read an account of one in the *Genie Civil* of a rope made by a French works for the Port of Brest. This paper spoke highly of the work done by the rope. In the author's opinion the rope suffered from the two serious defects indicated above.

Now, we come to the non-flexible type of rope, *i.e.*, the rope without any fibre centre. The simplest of this category is the spiral rope. This may appear somewhat arbitrary terminology, for all round ropes have a spiral form, but it is the nomenclature generally accepted in the trade. The spiral rope is in truth just a strand comprised of 7, 19, or more, wires. Such strands of 7 moderately thin wires are largely used for railway signalling purposes in England. Strands of 7 thick wires (rods) are used as guide ropes for the cages of mine shafts. Strands of large numbers of high breaking strain wires are used for bridges.

Strands of about 37 or 61 wires are sometimes used for the rail rope of bi-cable ropeways, but here the lock coil rope is generally preferred. The lock-coil rope is a more modern development. It is, like the spiral rope, a single-strand rope, and has in the case of the full-lock several outer layers of shaped wires, or in the case of the semi-lock coil an outer layer of alternatively distributed shaped and round wires. This type of rope gives a flat surface and therefore, providing the quality of the wire is equal to that of the round wire, a maximum resistance to abrasion. This quality of resistance to abrasion is wanted in most working ropes, but the

lock-coil rope has no hemp core, and if it had, the very locking nature of the outer wires would render such fibre core more or less abortive; therefore the premier mission of the lock coil rope is as the standing rope of a bi-cable ropeway, *i.e.*, the rope which is kept taut to carry the wheels of the waggonettes. However, the author has seen lock-coil ropes in use for winding purposes in coal mines, but they necessitate the use of drums of a very large diameter.

The flat rope is probably becoming a thing of the past. It is made of a number of four-strand wire ropes twisted in alternative directions and bound together side by side by interlacing wire strands.

How to Measure Wire Ropes.

There are often misunderstandings on this point, but on considering the matter it will be appreciated that a section of the rope should represent a circle of which the circumference will be coincident with the extreme outer edge of each strand.

Uncoiling or Unreeling Wire Rope.

Wire rope may be simply coiled or wound on reels. One must carefully avoid the formation of kinks when uncoiling or unreeling a wire rope. Should a kink be formed, it cannot be taken out by twisting or pulling, and the rope should not be put to work. Nor should a wire rope be uncoiled as though it were a rubber hose or a hemp rope. The coil should be lifted on its edge and unrolled. It is preferable, of course, to use lifting brackets, but in the absence of these the reel may be set up on blocks of some sort so that it can rotate.

Seizing.—It is advisable to give the end of a wire rope at least two separate seizings to prevent unlaying. Unlaying would naturally render the rope useless. The seizing should be done with annealed iron wire wound tightly in the form of a helix.

Fibre Centres really provide no additional strength but serve to give flexibility to the rope and to provide a cushion to preserve the shape of the wire rope in service when the wires are compressed together by a heavy load. The strength of the materials of which the fibre centre is made has little significance, but the core must possess the two following qualities:—

(1.) Be absolutely regular in diameter. An uneven core will throw the rope out of balance and may make the rope break itself up.

(2.) Must be able to satisfactorily absorb the lubricant.

Fleet Angle.—The fleet angle is the maximum angle formed by the line along which the rope runs when at right angles to the axis of the winding drum and a line representing the position of the rope when running off the extreme end of the drum. It is desirable that this angle should be as acute as possible, not more than 1½ degrees. Perhaps this limit might be slightly exceeded in the case of a grooved drum of large diameter. A large fleet angle will cause an overlapping of the rope on the drum, which will crush and abrade the rope. If the barrel of the drum is smooth a layer of rope should always be left on it.

Some Causes of Rope Destruction.

The author then dealt with some of the causes of deterioration in rope, e.g., abrasion, flexation, vibration, and corrosion.

(1.) *Abrasion* can be divided into two categories :—

(*a*) Wear of the external surface of the outer wires, and,

(*b*) Wear of the internal wires.

The first of these happens at the point of contact, principally between the coils of rope on the drum and at the point where the rope rests on the head pulley, also from slip on the pulley. Slip occurs as the rope first reaches and leaves the pulley, being the result of bending the wires on the curved surface. The former, e.g., the wear between the coils on the drum, is generally avoided in the mining industry by grooving the drums and allowing a groove clearance of 1/16 in. to 3/32 in. according to the diameter of the rope. If this is not obtainable in the petroleum industry, a layer of rope can be left on the drum. In any case, petroleum engineers would be well advised to observe the rule of groove clearance in regard to pulleys.

Internal wear is caused by the compression of wires on each other, more particularly in passing over pulleys, and depends upon the lay of wires and strands. The rotating movement, more particularly in the case of ropes with fixed ends, is also largely responsible for this.

(2.) *Flexation.*—The steel is fatigued by bending as the rope passes over the pulleys, and this plays a great rôle in shortening the life of the rope. The plant should be arranged so that no portion of a rope should run backwards and forwards over more than one pulley. Reverse bending increases the range of the alternating stresses in the wires and reduces the fatigue limit and the life of the rope. Reverse bends are permissible only when no other arrangement of the drum and pulley is possible.

(3.) *Vibration.*—This is a factor which is often ignored. Vibratory effect is set up between the drum and the load when the engine is set in motion and the vibrations concentrate on the end of the rope near the load. There is no doubt that the alternating stresses of tension and compression thus created make the wire brittle at that point. The reason probably is that the micro particles rub together and break up the granular structure of the wire into a more fibrous one.

(4.) *Corrosion* is undoubtedly a great danger and needs carefully watching. Corrosion may almost imperceptibly eat into a wire rope at one particular point, where the wire, under the flexing and twisting to which the rope is subjected during work, will snap. It must be remembered that, apart from the obvious bending to which the wire is subjected, the wire being in the form of a helix is subjected to a continual twisting stress. To obviate corrosion as much as possible, it is the ropemakers' duty not only to lubricate the heart of the rope, but also each successive layer of wire in the strand, and furthermore to use a lubricant that will adhere, for once the rope is made there is no oiling it internally afresh.

Application of Wire Rope to the Petroleum Industry in Rumania.

This is a field which, from the wire rope manufacturers' point of view, has really been very little explored. It may seem an exaggeration, but probably at least twice the quantity of ropes are consumed on the Rumanian oilfields as compared with what need be used.

The author first dealt with the vexed question of baling ropes. The majority of baling drums and pulleys that the author had come across seemed to have diameters fluctuating from about 16 in. to 24 in. The following ratios of diameters of the wire comprising the rope and of the rope itself in regard to the diameters of the pulley and drum are generally accepted. Rope, say, 1/60th to 1/80th of the diameter of the pulley or drum. Wire in the same, say, 1/800th to 1/2000th the diameter of the drum or pulley. The author took for his illustration the least severe of these ratios, which would necessitate the adoption of the following standards in Rumania:—

For Drum Diam.	Diam. of Rope	Diam. of Wire
16 in. ..	6½ mm. or ¼ in. ..	0·5 mm. or 25 gauge.
24 in. ..	10 mm. or just over ⅜ in. ..	0·76 mm. or 21½ gauge.

Whereas the petroleum producer was almost invariably using—

Diam. of Rope	Diam. of Wire
18 mm. or just over ¾ in. ..	1·2 mm. or 18 gauge.

If, however, ropes to suit the pulleys were used, they would not stand the abrasion against the well casings. For the latter purpose the thicker the wire the better. The practice in the Russian oilfields was to use 4 ft. baling drums and 5 ft. overhead pulleys, which enabled the use of the following ropes :—

Diam. of Rope		Diam. of Wire.
16 mm. or just over ⅝ in.		1·8 mm. or 15 gauge.
	and	
18 mm. or just over ¾ in.		2 mm. or 14 gauge.

However, wire ropemakers must take matters as they stand ; obviously any alteration in machinery standards in Rumania could only evolve gradually.

In the matter of the baling rope the ropemaker must endeavour to produce one sufficiently flexible to stand the acute bends over the drums and pulleys, and with sufficient toughness to withstand the severe abrasion which takes place against the walls of the casing. There was one point where possibly many petroleum producers could immediately effect an economy in baling ropes. The author had noticed in most cases the drum and the overhead pulley gave reverse bends to the rope. One of the recognized tests of wire is the flexion test, in which the wire is bent backwards and forwards to an angle of 180° over a radius of 5 mm. The normal baling rope here is made of 18 gauge wire. It is considered in the trade that 22 of the above mentioned bends represent a good test for this gauge of wire. To how many bends were the wires of a baling rope subjected in the course of a week's work ? It would soon reach hundreds of thousands. The author did not mean to suggest that the bends to which the rope is subjected are so severe as those to which the wire is subjected in the flexion machine, but the principle was the same. Now, this can be avoided, even with the existing installations.

Drilling Ropes.

In this field the author considered there was the greatest scope for improvement in constructions. A variety of drilling rigs were in operation in the Rumanian oilfields on which a longer life could be given the ropes if an alteration were made in the construction. Consider a few types of rigs in vogue. First the Foraky. Here we have two ropes, fixed at both ends, viz. to the rocker and the drum. These ropes will suffer from a certain amount of flexing around the pulley, and a lot of vibration towards the rocker beam. Both of the ends being fixed, one can, as already indicated, use a Lang's lay rope, which by its flexible construction is better fitted to withstand at least the flexing around the pulleys to which reference is made above.

Then there is the Peiner type of rig, in which one rope works as on the Foraky, and where again a Lang's lay rope could be used. The other rope (the jerker line) were better made of spiral construction, as here flexibility plays no rôle.

The third rig is the Indian. Here, obviously, two of the ropes should be of the non-flexible type (say spiral) and the third a Lang's lay rope.

It will thus be seen that at least the percussion drilling ropes in use on the Rumanian oilfields can probably be improved.

DISCUSSION.

The Chairman, in opening the discussion, said that he felt that the sequence of importance of the destructive efforts upon wire ropes given by the author was open to question inasmuch as discarded ropes were often seen showing no trace of abrasion yet with wire strands breaking out in short lengths, which he credited to fatigue in bending—the equivalent of flexation in the wording of the author.

The snapping or whipping effort resultant from careless release and picking up is sufficiently serious to obtain separate classification, although in effect it is a combination of fatigue and vibration.

He suggested that fatigue by bending was the paramount destructive effort and that abrasion, corrosion and vibration were of secondary importance and, moreover, subject to abatement by care.

That the author appreciated the point was evident from the recommendation to use pulleys of 60 rope diameters.

The Wire Rope Research Committee, in the second report, show that endurance of wire under continuous bending varies with the diameter of the pulley over which it is bent and that similar rope under a continuous bending test failed after

50,000	turns	over a	6	inch	pulley.
270,000	,,	,,	10	,,	,,
1,000,000	,,	,,	14	,,	,,

The best results were obtained over pulleys of 45 rope diameter.

One million bends applied to a baling rope making 10 to 11 runs per hour over one pulley and a drum entail 1,000 bends per day and, other factors neglected, the rope would last for a thousand days, say 33 months.

This is unknown in practice.

Locally, the life of a rope varies from ten days to six months and the speaker suggested that the main cause of premature destruction is to be found in the fact that one inch diameter ropes were generally winding upon drums of 14 to 20 inches diameter and running over pulleys of 20 to 40 inches diameter with at times an intervening pulley of even smaller size.

The practice of using this intervening or riding pulley is indefensible, as it entails 50 per cent. more bending effort for each run and reduces the life of the rope proportionately, for it has been demonstrated that partial bending of 20° is as bad as that of 180°.

Looking back it is difficult to appreciate that the ropes of to-day are giving better service than those of twenty years ago, yet the author shows that effort for improvement is not lacking on the part of the ropemaker and one may deduce from the paper that it is appreciated that existing working conditions should be modified so suit the rope.

The outstanding defect in the diameter of the winding drums and pulleys should be remedied by increasing them to at least 40 inches where 20 to 25 mm. diameter ropes are in use.

In baling drums and pulleys no difficulty is presented, for in Russia such have for long been of 5 ft. diameter.

In the matter of drilling machinery the remedy lies with the makers and one must look to such organizations as the American Standardization Committee to initiate reform.

When effected, operators may reasonably demand that ropes primarily withstand a tensile strain of 80 tons per square inch and 365,000 bends over a 45 rope diameter pulley, which will ensure reasonable strength and one year of work under normal conditions.

A margin then remains for adapting the rope to resist the destructive efforts of secondary importance.

The speaker added that he failed to appreciate the disastrous effect credited to reverse bending over drum and pulley, as it was difficult to imagine that rope in the form of a helix did not turn in its travel of 30 to 40 metres between drum and pulley.

Mr. J. T. Hayward said that he would like the author's opinion regarding the correct lay of rope—that is to say, right hand or left hand—that should be used for various purposes. A rope interests the operator from several points of view, and, in addition to the question of first cost, life and strength, there is, for instance, the comparative tendency two ropes of different lay may have to unscrew the tools : leading to a fishing job. In regard to cable tool drilling he believed that the general practice was to use a line of left hand lay, and was of the opinion that this was wrong and that, with the ordinary right hand tool joints, a right hand rope should be used.

Suppose a rope was being used on a Standard Cable rig, the upper end of the line being attached to the bull wheel and the lower end babbited into the rope socket. With the beam running there will be a cyclical variation of load in the line which will in turn cause a varying couple to be applied by the line to the rope socket. The tools being free to turn, but possessing angular inertia, will oscillate

about a mean position and the couple applied by the rope to them will be alternatively clockwise and anti-clockwise. Now the axial load upon the joint between the rope socket and the top of the Jars or Sinker will be practically equal to the tension in the rope immediately above the rope socket. When this axial load is great, it will, due to the friction between the threads, tend to lock the joint and prevent it from unscrewing. It will, therefore, be the couple exerted by the rope when the tension in it is small that will be effective in unscrewing the joint, should this by accident have become slack. A left hand rope exerts when unloaded a couple that in plan is anti-clockwise and such a rope will therefore if used as a drilling line with right-hand tool joints tend to unscrew the rope socket, while a right-hand rope would tend to set it up. This conclusion was, he said, the reverse of what he believed to be the usual theory.

One other point regarding lay. Attention has been recently drawn by the American Standardization Committee to the fact that the end of the drum to which the rope is attached is of importance. It is stated that if, for instance, one stands behind the ordinary rotary draw-works drum the rope should, if a left-hand one, be attached to the left flange of the drum, and if a right-hand one, to the right-hand flange.

Referring to the interesting point raised by Mr. Dabell as to whether a wire line passing over two sheaves some distance apart could be considered to be bent in opposite directions, and the life of the rope in this way shortened as the author had stated.

Mr. Hayward said that, having seen this statement frequently made by rope makers, he had carried out tests on several ropes working on baling wells and passing in a reverse direction over crown wheels, 20 to 30 metres from the winding drum. Markers were placed on the rope and showed that as a fact a section of the rope did not rotate in passing from the pulley to the drum or vice versa, and that therefore if these were arranged so that the rope was wrapped in opposite directions it could truly be considered as being subject to reverse bending.

From what the author has said regarding the Lang's lay, it would appear that such a rope would make a suitable casing line.

Mr. A. Jean Fedorowicz said that left lay drilling cable when lifting turned the drilling bit to the right, and returned to its normal state when the bit struck the bottom and allowed the drilling swivel to operate.

Mr. T. P. Perrott said that the so-called " Hamplemann " rope of the Indian rig of 36–38 mm. diameter seldom drilled more than 300 metres without giving trouble, e.g., in a 600 metre well sometimes three of these expensive ropes were destroyed.

He welcomed the statement of the author that the whole trouble was probably due to the use of the wrong type of rope, and that by using another type a considerable saving would be effected; therefore, he asked for details of the rope that should be used.

Mr. Leslie Little said that the author, in his description of tests made, only included the bending backward and forward a certain number of degrees of single wires. There was no mention of torsion test. In Baku, a good many years ago, wire ropes were taken to pieces and each individual wire submitted to a torsion test. One end was gripped in a stationary vice and the other end gripped in a revolving wheel, the wire was submitted to a certain number of turns until it parted, and each wire was submitted to the same test, and according to the number of turns the rope stood it was considered a good or bad one. These tests were made upon baling, not drilling, ropes and he asked the author whether such tests are still considered good practice.

Mr. P. R. Clark, in reply, said that Mr. Dabell mentioned that the number of bends the wire rope could stand under certain conditions could even reach a million. Twenty-two is an extremely severe "laboratory" test. It is a standard which is set up in rope-making circles—a purely arbitrary standard. 5 mm. is the radius used, and it enables one to get through the test quickly. For example, 1·8 mm. wire will stand about fourteen 180° flexions only. With 18 gauge wire 22 bends represents a fairly flexible wire. When you get flexions over a pulley which has a radius of perhaps 600 millimetres that is quite a different question, and the number of flexions may reach hundreds of thousands. As regards reverse bends, there is no direct analogy between the bend on the flexing machine and the bend over the pulley. The latter is nothing like so severe in radius and actual coincidence in the position of the wire.

As regards the question of lay, it makes no difference in Rumania whether left or right hand lay is used, except that to enable one to splice two pieces of rope together it is necessary that they should be twisted in the same direction.

In percussion drilling, as it was carried out in Russia, where a string of tools is threaded in one direction, it is necessary to have the rope holding them twisted in the opposite direction, otherwise the natural recoil of the rope would tend to unscrew the tools.

Mr. Perrott asked for details of the Lang's lay rope, and this was given by an ocular demonstration. The Lang's lay rope provides two great advantages over the ordinary lay rope :—

1. In the former a bigger surface of wire is subjected to abrasion; in other words, the wear is distributed over a larger surface. The individual wires wear out more slowly.

2. The wire being at a much more acute angle to the diameter of the rope gives a much easier bend.

According to the recognised tests in the flexing machine the wire must stand exactly vertical to the cylinder. If you put the wire in at right angles to the cylinders, it will give a minimum of bends; if you put it a little to one side it will stand more bends—the nearer you get the wire to the horizontal the more bends it will stand.

Referring to Dr. Woehrnle's tests—if the longevity of the Lang's lay rope is represented by the figure 100, the ordinary lay rope must be represented at 26 and the cable lay at 14.

In all these there are four tests generally recognised in the wire rope industry:—

Tensile Strength.
Torsionary Resistance.
Flexibility.
Elongation.

There is no doubt that the torsion test is a very important one. One objection raised to the bending test is, that you are only testing a minute part of the wire, whereas in testing for torsionary resistance a length of 100 times the wire's diameter is taken, or in other cases an 8 in. length is taken for all gauges of wire.

The Chairman said that the present meeting between the rope-maker and the rope user in itself constituted the first step toward improvement, and moved a vote of thanks to the author for his painstaking effort.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

THE FIFTH GENERAL MEETING OF THE RUMANIAN BRANCH of the Institution of Petroleum Technologists was held at the Industrial International Club, Ploesti, on Friday, February 25th, 1927, Mr. A. Frank Dabell, M.I.Mech.E., Chairman, presiding.

The following Paper was read :—

Water Problems in Oil and Gas Fields,

By J. M. WALSH.

Encroachment.—The Author drew attention to the action of advancing water in trapping of oil and the forced abandonment of wells owing to the high lifting costs entailed, before normal recovery is completed.

Infiltration.—In reviewing the ways by which water gains access to wells he related a recent experience at Moreni where several strings of casing were found to have been perforated by a hole of approximately one inch in diameter. It was assumed that a sand pit existed in the outer column through which water under pressure had found its way and with the sand in suspension had then perforated the remaining strings.

Migration.—When a water sand is found between two productive strata the failure to confine the water may lead to the loss of both strata, as it may flood the upper as readily as the lower zone. This applies particularly to gas sands which, being dry, offer less resistance to water than those containing oil.

The Author deprecated the practice of drilling through an oil sand.

Casing.—It is important that close co-operation should be practised in drilling and casing of wells in producing fields, otherwise one operator may offset the good work of another, although individually both are working on sound lines.

Analysis.—Investigations show that water from different strata vary in chemical properties and therefore can be distinguished by their composition.

Analysis is used successfully in California and Kansas as a guide to routine operations. Some operators realising the importance of chemical analysis in determining the source of water take samples whenever possible, and if there be no immediate need for the data they are labelled and stored for use if a water problem arises.

Levels.—The recording of fluid levels will assist the determination of the source of water in a well.

Tests.—The source of water can be sometimes decided by filling the hole with heavy mud fluid and bailing from the top of the fluid until clear water appears. The bailer may then be run to certain depths to feel for the mud and the surface of the undiluted mud when found is usually near the spot of entry of the water.

This method may indicate whether the water is coming through a casing leak around the shoe or from the bottom of the hole. Perhaps the most satisfactory test to determine the source of water is to start from the bottom of the hole and plug by stages, eliminating the various sources in this way. A method which has been successfully used in water shut-off tests is to run a smaller string of casing inside a larger one (say 6 in. inside 12 in.) and to use a packer to pack off between the 6 in. and 12 in. at the bottom of the hole. The fluid is then bailed from the smaller diameter casing and if no water appears below the packer it is conceded that the water is shut off at the shoe.

The objection to this method is that if there are defects in the larger or water string they will not be observed.

Mr. E. J. Dailey has suggested a method to be used where long strings of large diameter casing are employed to shut off water. He suggests that a high pressure pump be connected to the top of the water string and a pressure be put against the fluid inside the casing. This pressure to be equal, or greater, than the pressure which would be obtained by bailing out more than half the fluid, as is customary at the present time.

Mr. Dailey contends that if water is coming behind the casing shoe or there is a leak in the casing the pressure will drop as the fluid is forced back into the formation, or around the shoe. This would indicate that the water is not shut off. The great advantage of this method is that there would be no danger of collapsing the casing.

Cementing.—In *Oil Weekly*, issue of Sept. 17th, 1925, there is an interesting article on cementing casing through perforations to protect oil sands.

This article states that water strings are often damaged through friction of drill-pipe after water shut off has been made, and recommends that, when perforated pipe is run on the producing string, the space between the blank part of the producing string and water column be cemented, *i.e.*, the part of the producing string above the perforation.

The practice of using long strings of perforated pipe through oil and gas sands deserves careful consideration.

In Ceptura oil field one company is reported to have recently run 250 metres of perforated pipe through a series of sand and sandy shales. Should undetected water exist in some of these sands, it is possible the well might be lost.

Summary.—The problem of water in oil and gas sands is one which cannot be covered in one sitting and should be given further consideration.

Water is without question one of the greatest obstacles oil operators have to overcome. The rising cost of drilling wells makes it imperative for companies or individuals drilling side by side to work together, to exchange ideas and to make every effort to prevent oil and gas sands from being flooded.

The use of better casing and the practice of better work in cementing and making formation shut-offs, together with the keeping of reliable well records should go far toward eliminating danger and damage.

DISCUSSION.

The Chairman, in opening the discussion, said, that although every water encountered in drilling had some characteristic feature, the fact remains that little is known of such in the proven fields, and there was no authority to whom one could take a sample of water and obtain a declaration as to its horizon or origin.

Characteristic features may not necessarily be confined to the salts carried by the water. The knowledge of the temperature, static head, rate of percolation and nature of containing bed was equally valuable and showed a necessity for close contact between Chemist, Engineer, Geologist and Driller.

For instance, it was not generally known that in the North Moreni field water in contact with the second oil sand could readily be distinguished from that of the third, inasmuch as the former registered 15 deg., and the latter 20 deg. Beaumé scale.

Responsibility for lack of data must rest with the geologists, who would readily recognise characteristic features were they in closer touch with field operations, and it was surprising that the higher administration did not appreciate the value that would accrue from trained thought applied to minor phenomena.

The speaker deprecated the use of cement for water shut-off purposes where plastic clay could be used in its place. He advocated the more general practice of the Wallen system of filling the bottom of the hole with clay and using the casing column filled with water as a ram to force the clay up and around the column itself.

Mr. E. T. Hancock said that he was in agreement with what had been said regarding the necessity for keeping close watch upon

different waters, but in defence of the geologists it had to be recognised that it was often impossible for them to follow the operations of particular wells.

He related the experience of a well at Baicoi, which drilled through a bed of two or three metres of shell fragments lying 15 to 20 metres in the Meotic, found almost immediately an oil sand. During the time of preparation for testing water rose and flowed over the mouth of the casing. The total depth of the well was 1420 metres. He suggested that the origin of this water must be at Bustenari, where the Meotic formation is exposed at the surface. He drew attention to the fact that drillers sometimes referred to "dry formation" because the water level had fallen whilst in fact the fall of water level indicated that the pressure due to the column of drilling water was greater than the hydrostatic pressure of water in the sand and the opposite condition prevailed—the well flowed, when the hydrostatic pressure in the sand was greater than that of the water column.

In drilling through sediments which have openings of Sub-Capillary size they appeared dry, although they contain a higher percentage of water than some coarse sandstones, because they have a higher percentage of pore space. The sub-capillary openings are so small that the film of water attached to the walls of the opening is equal to half the diameter of the opening which, filled with water, is not free to move.

Although the sediment is apparently dry, it has just as high a percentage of water as coarse sandstone.

Mr. T. P. Perrott said that he thought the Author, in his reference to formation water shut-off, failed to express the importance of the use of long casing shoes.

Whereas the majority of local operators used shoes of from 1 to 1·20 metres in length, shoes of 5 metres were more efficient, owing to the longer point of contact between shoe and formation.

He appreciated the use of clay for water shut-off in long distances between water and oil, but in Tontesti field, where only 5 to 10 metres intervene, cement is more suitable to anchor the shoe to stone.

Mr. R. Walters, speaking with reference to the value of water and analyses, especially their use in California and Kansas, said that in these areas the results obtained have been based largely upon the varying amounts of Na, Ca and Mg of the positive radicles and $ClSO_4$ and CO_3 of the negative. In some fields it has been found that the percentage of SO_4, for instance, increases regularly with the depth and in others decreases.

A number of analyses of water from the local Pliocene beds have been made, and have shown nothing but NaCl. If, as seems

probable, this holds true for all Pliocene beds in this district of Rumania water analyses will prove of much less importance than where different salts are found in the water. It might very possibly serve as a guide to distinguish between Pliocene and Miocene waters, however, as the Miocene waters, in view of the amount of gypsum occurring throughout the series should contain $CaSO_4$.

Mr. J. F. F. MacQueen said that there were cases in which operators acting conscientiously suffered through lack of co-operation on the part of others, and it seemed to him that it was for Mining Departments to protect such operators by ensuring that local regulations were strictly adhered to by all. Though it was difficult to combat occurrences of deliberate delusion of the authorities, he thought it would be beneficial to operators if they were all obliged to furnish full reports of their wells to the Mining Department for reference purposes.

Referring to the Wallen system of shut-off, he quoted a case in Egypt where a very strong water was effectively shut off by this method. The water was accompanied by a heaving sand which gave rise to doubts as to the efficacy of clay alone. However, several tons of clay balls of about three inches diameter were dropped in the well one by one, and the column, with a wooden plug inserted in it, held in place by the clevis pin, lifted as high as the derrick permitted. This served as the hydraulic ram when the casing was lowered into position, and forced the clay well up round the back of the shoe. To avoid any danger of bursting, the plug had a small hole drilled through it to relieve the pressure accumulating.

Since observing the success of clay as a shut-off medium in this particular case he was strongly in favour of its use wherever it was possible, as being preferable to cement.

The Chairman's remarks about water entering from extraneous sources, reminded him of a well also in Egypt, where water, only noticed at irregular intervals, was found to be sea-water washing over the derrick floor. This derrick was built at the end of a pier some fifty metres from the shore, and the water was entering behind the working column.

Mr. Albert Miller said that he was of the opinion that water shut-off could be made with clay in practically every case.

In Poland they had water shut-offs at 1000 metres and deeper, always making successful jobs with clay inserted under the Wallen or similar systems.

He believed that more water trouble could be solved in that manner, especially if the liquid column of mud behind the casing is left to settle a few days before bailing out, as this furthers a tight seal.

It is not always safe to rely upon the analysis test made on the water to determine the source from which it is coming, as two waters coming from quite a different source may give practically the same analyses, especially if the analyses show only an ordinary salt content. If, as in some cases, the water contains many different radicles, if the tests are carried out carefully, it is possible to ascertain the source of the incoming water.

Mr. R. Bolton said that in his experience of shutting off water in gas-fields he had failed when using cement.

In wild cat wells he had to test each sand, sometimes one lying but 5 metres below another, and water often intervening.

Using clay under the Wallen system he had been able to make water shut-off, test a sand and free the same column four times before loosing it.

Where casing was set in cement he had lost all his strings and failed.

The Author, in his reply, said that his company had adopted practically universally the use of clay instead of cement in wild cat wells, or where they were not sure of finding oil, and it was necessary to maintain large diameter casing.

Where heavy gas pressure had broken loose they had found that cement held back water better than clay. In the matter of dry sands he had the admission of a driller of 25 years' practice that when drilling with a wet hole he could never tell definitely whether a sand contained water or not.

He appreciated the point raised upon the value of longer casing shoes and under recent practice the length was being increased.

A vote of thanks was accorded the Author, and the meeting terminated.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

PERSIAN BRANCH.

THE INAUGURAL MEETING OF THE PERSIAN BRANCH OF THE Institute of Petroleum Technologists was held at Abadan, on April 13th, 1927, when the following Paper was read :—

The Thermo-Dynamics of Oil Refining as Bearing on the Design of Plant.

By W. C. MITCHELL.

The importance of heat and heat conservation in the operating and economy of an Oil Refinery is a by-word amongst oil technologists generally, but the paramount necessity for a complete and co-ordinated understanding of the various reactions and operations which depend upon changes of temperature and pressure has not in the past been sufficiently appreciated.

The preparation ready for the market of the various grades of oil from the crude may roughly be divided into two classes of operations, namely, distillation and chemical treatments. The latter is a life study for the most experienced chemists, supported by the research establishments and laboratories of the world. The former is equally a field for study of the most highly trained and capable engineers and physicists, but hitherto has not received anything like the same amount of attention and study.

The laws and relations of thermo-dynamics and physics and their implications and corollaries must be thoroughly understood before an intelligent grasp can be obtained of this aspect of the oil-refining industry.

Before anything can be accomplished towards the refining of oil, power has to be generated for the mechanical handling and transfer of the oil from place to place. This usually involves the operation of steam raising plant, and so generally used is such plant in all industries and so fully has the importance of thermal efficiency been realised, that years of time and many thousands of money have been spent in exhaustive study of this subject and in the acquisition of designing and operating technique calculated to obtain the utmost overall thermal efficiency from steam plants. This has led to the common use of superheaters, economisers, pre-

heaters, both air and water, induced and forced draught, radiant heat absorbing water walls of combustion chambers, and countless other accessories and appliances.

The oil refiner finds these all ready to his hand, and therefore reaps the advantages sown by the intensive study applied to this subject over many years. When, however, we turn from this generally used plant to the particular plant used in the oil industry we find that a very different state of affairs exists. It may be that the oil industry is of more recent growth, or that from the very nature of its association with the speculative in industry the design of distillation plant is relatively haphazard and to a large extent governed by rule of thumb and precedent. It would, perhaps, be more accurate to say that this was the case until recently, for it cannot be denied that throughout the oil world there has of recent years grown up a determination to pay more attention to the proper designing of distillation plant in accordance with known physical and thermal laws and relations. This tendency has no doubt been the result of the opportunity that the industry has had, particularly since the war, to sit back and survey the position and to consider where it is travelling, coupled with an undoubted scare, whether engineered for ulterior motives or not, that the oil resources of the American continent are not inexhaustible, and that there is every reason to cut down the excessive waste and loss which had always been associated with an industry living often for the sole purpose of making money rapidly while oil could be obtained from the wells.

This better tendency is reflected in the improvements that are being suggested and adopted for the more efficient and economical distillation of oil, and it is proposed in this brief paper, prepared at very short notice for the inaugural meeting in Abadan, to touch on some of these improvements, without attempting to discuss them in detail, with a view to stimulating interest and promoting further investigation and consideration of these important aspects of the science of oil refining.

It is unnecessary to dwell on the evolution of distillation plant from the plain shell still on brick settings designed in a haphazard way, through the various improvements that have taken place in general design and the incorporation of heat exchangers for the saving of fuel. The importance of this regenerative use of heat has led designers and plant manufacturers to undertake a systematic study of the laws and conditions governing heat transfer from one fluid to another and the way in which the heat transfer rate varied with velocity of flow, viscosity of fluids, surface condition and thickness of the metal between fluids, turbulence of flow, etc. Further complications were met with due to the increase in vapour

pressure and the consequent tendency of the cold crude to gasify when heated. This rendered it necessary to maintain considerable pressure on the crude oil to prevent this gasification and consequent reduction of heat transfer rate.

All these conditions have been exhaustively studied in the research establishments working for, and attached to, both oil companies and manufacturers of plant, but chiefly of the latter. Very considerable expenditure by these manufacturers has enabled some of them to have practically a monopoly of the information enabling design of heat transfer plant for the oil industry to be undertaken with comparative certainty of results, and this naturally has been reflected in the enhanced price that they can legitimately obtain for their products. Outside of these few concerns the ability to design with certainty is rarely found, although, of course, the general conditions governing the operations are well known. There is a great deal of difference, however, between the knowledge of the general theory and the ability to design on paper a heat exchange equipment to meet any given set of conditions, and until results of research are published or, alternatively, a systematic study of the subject is undertaken, coupled with a large amount of experimental work, the oil refiner will not be able to design his own apparatus with as great a certainty of achieving results as the proprietary manufacturer.

The design of condenser equipment and gas coolers is almost on all fours with that of exchangers, although here the theory and practice of steam condensers is very similar, and is helpful. As is well known, condensers were originally used in the oil industry with very little knowledge of the conditions governing their operation. The adequate water supply, traditionally supposed to be the necessary accompaniment to a refinery, is probably responsible for the apathy displayed towards condenser design and improvement, but considerations of power lost in circulating unnecessarily large volumes of water, and the enormous losses resultant on inefficient condensation and insufficient cooling of the distillation products, have resulted in modern distillation plants being equipped with highly efficient and properly designed tubular condensers and coolers, employing relatively small volumes of water artificially cooled through large atmospheric cooling towers. In cases where crude is run to relatively small residues, vapour exchangers are sometimes used as primary condensers, using the oncoming crude as the cooling fluid, but usually the complication and difficulties of this method have not warranted its general adoption, although undoubtedly it will be more used as time goes on.

Improvements in the exchanger and condenser equipment have been mentioned above, but perhaps the most important improve-

ment in distillation plant has been in the development and operation of pipe still units, involving the heating of the oil in direct fired tubular heaters under moderate pressure and the flashing of the heated oil into a fractionating column or series of columns. The whole of the operations in such a plant is a constant series of heat interchangers, with the continual varying of the physical states of the various fractions of the product, and very exhaustive experiments were necessary before a certain knowledge of what goes on in such apparatus could be arrived at.

Anything like a detailed survey of the subject of fractional distillation is beyond the scope of this brief paper, as it involves elaborate considerations of vapour pressures of multiple mixtures, and the relative proportions of the various constituents in the liquid and in the vapour space. It may be stated briefly, however, that fractional distillation is based on the fact that, when a liquid consisting of a mixture of several components is heated, the vapour space is richer in the more volatile components than is the liquid. The action of a fractionating column, therefore, is such that the ascending vapour is intimately contacted by descending liquid, so that at each stage equilibrium between the liquid and vapour is obtained, involving an interchange of constituents, the vapour becoming successively richer in volatile components, while the liquid takes up the less volatile components from the vapour. The temperature will, of course, vary from stage to stage, depending upon the phase compositions.

With this brief general explanation I propose to confine my remarks on this subject to outlining the cycle of operations in a typical pipe still unit fitted with fractionating columns of modern design.

The oncoming crude is first passed through a series of heat exchangers, through which are also pumped the final residue and usually the hot kerosines and gas oil fractions. The heat imparted to the crude in these exchangers is usually sufficient to flash off in suitable vessels from 8–10 per cent, of the crude, and the vapours thus flashed off are introduced at a suitable point in the first column to insure that all traces of the heavier fractions carried off in the flashed vapours are stripped in the column. Sufficient pressure is kept on the crude during its passage through the exchangers to prevent appreciable gassing, as this would seriously interfere with the heat exchange efficiency.

The residue from the flash tank, representing about 90 per cent. of the crude, is pumped through a direct fired tubular heater and flashed into the first column over a diffuser plate or cone. Pressure must be kept on the oil while passing through the pipe still heaters to prevent gasification, which would detract from the efficiency of

heat input, add to the power expended in pumping and possibly lead to damage to the pipe due to overheating.

The sensible heat in this oil is expended in evaporating a further 15–20 per cent. of the crude, which passes as a vapour up through the plates of the column, together with the 8–10 per cent. from the preheater flash tank, to the condenser. A reflux condensed overhead from this column is pumped into the top of the column, the quantity of this reflux being regulated by a thermostatically operated valve in order to keep the temperature at the top of the column constant. The end point of the overhead is dependent on this temperature, and the throughput and quantity of heat put into the oil in the pipe heater must all be correlated to the quantity of reflux to give the desired amount of overhead with requisite end point.

The bottoms from the No. 1 column are pumped through a second heater and introduced into the second column, where a similar action takes place, the overhead from this column being the next lighter product, namely, a blend stock or light kerosine as required.

The amount of overhead desired from the second column and its composition determines whether or not a third column is required, with its own pipe heater. Where only a small amount of overhead is required from the second column a third auxiliary or stripping column is added, in which arrangement liquid from the bottom of the second column is pumped or steam lifted into the third column from whence it passes down through the plates. A re-boiler is fitted to the bottom of this third column, the bottoms being pumped through a small pipe heater and re-circulated back into the column. The vapours at the top of the column are passed back into the second column, and the various grades of kerosine and gas oil are topped off the trays of the auxiliary third column. In the event of a gas oil not being required from the last column, a by-pass is arranged on the re-boiler circulating system to pass the bottoms into the second column and so into the residue.

The final residue is taken off from the bottom of the second column, and, together with the kerosine and gas oil, passed through exchangers to heat the oncoming crude.

The columns referred to are those containing a series of plates fitted with bubble caps, each tray being flooded with liquid, through which the vapours pass in the form of fine bubbles, and subsequent spray with consequent intimate mixture.

As previously stated, the heavier parts of the ascending vapours are condensed and absorbed by the liquid, while the lighter parts of the descending liquid are evaporated and carried up with the vapour, the actual composition of the vapour at any point being

dependent on the temperature at that point for any given throughput and heat input into the column.

It will thus be seen that the whole of the operations of a pipe still unit are a series of thermal reactions and interchanges. The tendency of all modern distillation plants is towards direct heating in pipe stills and direct fractionating in columns, combined with elaborate heat exchange equipment.

Another type of plant used in oil refining, involving a thermal process, is the Sharples plant, for the de-waxing of lubricating oils. In the manufacture of master lubricant from paraffin base crude residue a cut is obtained by distillation under high vacuum, consisting of that portion between a 30 per cent. and 10 per cent. residue or thereabouts, according to the crude. This cut contains the so-called amorphous wax or wax in the non-crystalline state, although it has now been shown that this wax is not really amorphous but crystalline in a different and smaller form from the normal crystalline wax. It is not possible to remove this wax by means of the conventional filter press, so other means have to be adopted. The amorphous distillate is first diluted with about 140 per cent. of naphtha, heated to about 100° F., and subsequently cooled very slowly, at the rate of 2° F. per hour, down to a temperature of about –10° F. with occasional slight agitation. The cooling is effected in a large tank by brine circulation in closed coils, the brine being cooled by means of the ordinary ammonia refrigerating plant.

This slow cooling process causes the wax to become visible as a cloudiness of minute crystals. This wax is separated from the master lubricant by centrifugal action, the cooled solution being fed slowly into a Sharples centrifuge, together with a small quantity of hot water.

Among other examples of the part played by thermal reactions in modern oil refinery plant may be cited the high vacuum distillation of lubricating oils, employing a vacuum of the order of only 4 m.m. of mercury, and so reducing the temperature of distillation and consequently the risk of cracking; the recovery of gasoline from casing head and still gases by means of pressure and cooling; and the cracking of oils by means of high temperature and pressures. Enough has been said, however, to show the enormous part played by heat and pressure in the refining of oil, and the great importance to the oil technologist of systematic study and experiment as applied to their bearing on the design of plant.

REVIEWS.

Estudio Geologico del Terciario Carbonifero de Antioquia.—Emil Grosse. Berlin: Dietrich Reimer (Ernst Vohsen). 1926. 13×9¼, pp. xiv.+361. Geological Map, 16 Plates and 105 Figures in Text.

It should be said at once that the above Memoir contains nothing of direct interest to members of this Institution. There is no petroleum in the area studied, and little prospect of its discovery. Dr. Grosse's description of a part of the Republic of Colombia which had not been examined in detail until his visit will, however, be found interesting by geologists through its indirect bearing on oil problems in other parts of the country.

The Andes, on entering Colombia from the south, divide into three ranges, which form the Western, Central, and Eastern Cordilleras of that country. The trough between the Western and Central ranges is drained by the Cauca River. Parallel to, and not far to the east of, the Cauca, the Porce River occupies a longitudinal subdivision of the Central range. The area dealt with in the Memoir consists of a north-south strip between latitudes 5° 40′ and 6° 40′ N, bounded on the west by the Cauca, and on the east, as to its northern two-thirds, by the Cauca-Porce watershed.

Within this section of the Department of Antioquia is a coal-bearing formation, the extent and content of which it was desired by the Departmental Assembly and the Antioquia Railway to determine. To this end, Dr. Grosse studied the ground in the field from the end of 1920 to the middle of 1923, the bulk of the subsequent laboratory work and the preparation of the maps and Memoir being carried out in Germany.

The formations are described under three headings:—the Basal Complex, the Coal-bearing formation, and the Cover rocks. The geological succession is given as follows:—

Cover Rocks	Quaternary terraces.	
	Neo-Tertiary volcanics (Combia Beds) and sedimentaries, accompanied and succeeded by intrusions.	
Coal-bearing Formation	Upper, Middle, Lower	Eo-Tertiary.
Basal Complex	Eo-Tertiary plutonics.	
	Lower Cretaceous sediments and volcanics.	
	Upper, Middle, Lower	Algonkian, accompanied and succeeded by intrusions.
	Archæan	

The order and, indeed, the number of the formations, at least up to the Cretaceous, is determined by their degree of metamorphism. Whether this method is of much value in the lack of all knowledge of structure—and the Memoir dismisses the pre-Tertiary tectonics in just over one page—is, perhaps, open to doubt. The attempt at still greater refinement, in the ascription of certain rocks to the Archæan and others to various stages of the Algonkian, appears to the writer as a quite unwarrantable forcing of the evidence. The

uncertainty of the ascriptions is manifest in several places. Dr. Grosse himself at first placed his Upper pre-Cambrian rocks in the Palæozoic on the feeble evidence of their petrographical resemblance to a formation, believed to be of that age, in Argentina and Peru; and revised his decision on the equally feeble grounds that rocks of the same age in northern Peru have a different development. An even more striking example is furnished by the occurrence at Alto Buena Vista of what is described as a highly-altered basic diorite which, on grounds other than those of metamorphism, is assigned to the Eo-Tertiary, but is, apparently, petrographically identical with the "Archæan" amphibolites. It is only fair to add that the author himself at times sounds a note of warning, which, however, he seems to forget in his résumé, when he asserts that the amphibolites near Córdoba are "without doubt" of Archæan age.

In dealing with the Cretaceous and later rocks he is on safer ground, although the fossil evidence is still far from satisfactory. It is to be regretted that the examination of the vegetable fossils by Drs. Kraüsel and Schönfeld was still only in its preliminary stages when the Memoir was published.

The section on the tectonics of the coal-bearing formation is of much interest, but could not be usefully criticised without intimate acquaintance with local details. The constant use of the word "sobrescurrimiento" (German version, "Überschiebung"), which one is tempted to translate by "overthrust," for all kinds of reversed faults is rather confusing. It is only at the end of the section that it is defined as including other faults than overthrusts in the strict sense of the word. The note that, on the map, the name of each "sobrescurrimiento" is on the hanging side of the fault might usefully have been printed on the map instead of being buried deeply within the volume as a footnote.

Considering the object and scale of the Memoir, the treatment of the coals is rather disappointing. No microscopic work seems to have been done. Only proximate analyses are given, so that the C/H ratios are indeterminable, and it is impossible, for instance, to apply Seyler's classification. Using Parr's formula for the heat value of the pure coal substance, free of sulphur and ash, the average coal quoted on page 127 would fall within his Brown Lignite class. A similar calculation for Sample 9 on page 130 places it among the best bituminous coals. It is interesting to learn that Charpy and Godchot's experiments on the conversion of non-coking into coking coals by preliminary low-temperature treatment have been duplicated in this region by the natural action of andesite intrusions upon adjoining seams.

In the beautifully-produced maps Dr. Grosse seems to have fallen a victim to an undue desire for completeness. "It was necessary, therefore, to draw the boundaries between the stages more or less arbitrarily, in order to be able to carry out the colour-scheme of the map." This is dangerous doctrine, and its effects may be traced in more than one place. We are told, for example, that the region east and north of Sopetrán was explored only very superficially, and that its geological representation must, therefore, be taken as correct only in broad outline. Now, if we examine the map in 1Ba we find that, east of Loma del Común, the metamorphic aureole in the Middle pre-Cambrian, around the intrusion of lenticular granite, is cut into by an angle of Lower pre-Cambrian. If this is a piece of actual mapping, we have a very pretty instance of the way in which the sequence of geological events can be deduced, the interruption of the aureole in the Lower pre-Cambrian showing that the Sucumbi fault must have occurred after the intrusion of the granite. But when, bearing in mind the superficiality of the survey, we learn also that there is a question about the fault itself, there is some excuse or wondering whether this neat interruption was really observed, and whether

it was not put on the map because, according to the author's theories, it ought to be there. The writer confesses to a strong bias in favour of confining such speculations to the text.

To the same undue anxiety for completeness we probably owe the close contour intervals. For a "purely schematic representation" and an accuracy in altitudes which is not claimed to be much nearer than 50 metres, a 25-metre interval seems unnecessarily small. The map itself would have benefited by the employment of a wider interval.

There is a short reference to other mineral deposits than coal, of which gold and silver, and salt are the only ones of economic importance. The excellent index provides map references of all places mentioned, the only omission noted being Alto Requintadero in 1Bc. There are a few misprints besides those noted in the Errata, of which it is necessary to notice only those on pages 236, 248, and 250 (twice) where "anticlinal" should be "synclinal."

In spite of the above remarks, the Memoir is obviously a record of a piece of very thorough and conscientious observation. One may conjecture that Dr. Grosse is a petrological enthusiast, which leads him to pay perhaps a rather disproportionate amount of attention to the description of igneous and metamorphic occurrences. But future workers in this and related areas will build very largely on Dr. Grosse's foundations, and will owe him a debt of gratitude for the surprisingly large mass of really valuable information he was able to collect in the limited time at his disposal, and for the light he has been able to throw upon the constitution of an exceedingly complex region.

W. G. Weeks.

The Petrology of the Igneous Rocks. By F. H. Hatch, O.B.E., Ph.D., and A. K. Wells, D.Sc.

"Of the making of a text-book there is no end." We found ourselves so adapting the words of the ancient sage as we compared the new edition of this work with two of the earlier ones. Science moves onwards, not as the stars do, but in fitful jumps at irregular intervals. Thus, in the preface to the fifth edition in 1915, it was possible for Dr. Hatch to write: "This book has not been revised since 1892." The science of petrology had moved so far forward in the meantime that the work had to be re-written for the fifth edition. For the eighth edition it has again been necessary to re-write it, even though considerable alteration and addition had been made to bring the work up-to-date for the seventh edition in 1914. Dr. Wells now assists the original author in what is a serious piece of work. We do not think that we shall be in error if we say that in the last interval of twelve years greater progress has been made in the science of petrology than could be claimed for the earlier twenty-three years of this book's existence.

The great difficulty with a work of this kind is to keep it within moderate dimensions when so much new material is pressing for admission. The authors have exercised sound judgment in dealing with this problem, and though each section of the book shows a tendency to expand it still retains its handy text-book size and little of importance to elementary students has been omitted. Such students should make good use of the ample references to papers and more advanced works given in the footnotes.

In the seventh edition chapters were added on the Pyroclastic Rocks and the Metamorphic Derivatives of the Igneous Rocks, filling thereby a gap which was rather a weak spot in the earlier editions. Now we have other sections on the Consolidation of Igneous Magmas and on Cycles of Igneous

Activity in the British Isles. The student is also given some insight into the fundamental conditions governing the formation of rocks and rock-forming mineral by additions based on the experimental work done chiefly in the Geophysical Laboratory at Washington.

Another difficulty which the authors have met is the tendency for this subject to become more complex and mystifying to the student by what we may call the "fissiparous" nature of rock types. In the hands of the experts the number of names of rock types has multiplied exceedingly of late years. It cannot be said that these new names are, in general, either pleasing to the eye or the ear. The authors have not introduced many of these names, but by classifying types according to the geographical areas in which they occur have assisted the student very considerably in the initial stages of his work.

This text-book can certainly be recommended very highly to the British student of geology, especially of mining geology. It is a book which he cannot afford to neglect. Although the petroleum geologist works in the main amongst the sedimentary rocks, a sound knowledge of minerals and of the igneous rock types is essential. How essential it is we ourselves realised on one occasion when we found that a weathered mass of quartz-andesite had been mapped as a porous grit. Although the authors sometimes describe the effects that weathering produces in the igneous rocks, such effects are not always adequately dealt with. The changes in the appearance of the rock due to weathering are of more importance in the field than in the study, and the student must certainly learn to recognise his types in the weathered specimens which he may find in the field. This is sometimes a very difficult thing to do, especially in the damp tropics. The authors, however, will view any suggestion of this kind with concern. The book is already growing with the years and must continue to grow, and yet the dimensions of an elementary text-book must be kept within limits. ARTHUR WADE.

CHEMISCHE TECHNOLOGIE DE ORGANISCHEN VERGINDUNGEN. Edited by Dr. R. O. Herzog. Publishers: Carl Winters Universitatsbuchandlung, Heidelberg. Pp. 997.

This valuable Dictionary of Applied Organic Chemistry was first published in 1912, and is re-issued from Heidelberg in a móre extended form this year. The Editor has been assisted by an able body of collaborators, each of whom is a specialist in his own particular subject.

The sections deal with the following industries :—

Bitumen and Tar ;
Fats, Oils and Wax ;
Rubber and Gums ;
Carbo-Hydrates ;
Fermentation ;
Proteids ;
Coal Tar Colours ;
Essential Oils ;
Pharmaceutical Products ;
Explosives ;
Photographic Materials ;
Bleaching and Dyeing ;
Textiles.

The particular section which appeals to this Institution—*i.e.*, Petroleum, is written by Dr. Leopold Singer, and comprises a succinct summary of the winning of petroleum, its physical and chemical properties, theories of origin, the principles of distillation and refining, cracking, the manufacture of paraffin and lubricating oils.

Naturally, in so restricted a space the author has been unable to give more than the barest of summaries, and in consequence is unable to depart from very conventional lines of treatment. For example, the acid and soda treatment is the only one discussed and that in plant of the simplest type. Clearly in a dictionary of this type only a birdseye view can be given on the multitudinous subjects that are discussed, but as a general work of reference for the student of technology it has a decided value.

A. E. DUNSTAN.

LUBRICATION AND LUBRICANTS. Treatise on the Theory and Practice of Lubrication. By Leonard Archbutt, F.I.C., F.C.S., and R. MOUNTFORD Deeley, M.Inst.C.E., M.I.Mech.E., F.G.S. Charles Griffin & Co., Ltd., *London*. 36s.

As it is fifteen years ago since this book was last revised, the fifth edition, which is now to hand, has had to undergo very considerable additions and re-arrangement. For this purpose several other well-known authorities have collaborated in the preparation of special sections.

The first five chapters deal with the theoretical side of problems of lubrication and give a very complete and carefully prepared review of recent experimental work and of recent developments in the theory of lubrication. This is probably the strongest section in the book and is of great value.

Chapter six deals with the sources, preparation, and the chief properties of lubricating oils, both those of mineral origin and the saponifiable oils. A full treatise on petroleum refining is, of course, beyond the scope of the book, but the present section does not give adequate treatment to recent processes which affect the preparation of lubricating oils, particularly the Sharples dewaxing process, which is now used to such a large extent for the preparation of the better class filtered Cylinder Oils and also to the Long Residuum process and the Contact Clay Filtration process, which has now to a very large extent superseded percolation treatment as a means of refining both residual and distillate lubricants.

The section dealing with the classification of mineral lubricating oils is very weak, neither the system of classifying dark cylinder oils on the fire point or of distillates on the sable increase being mentioned, in fact if one attempted to read an American refiners list of lubricating oils, there is nothing in the book which would guide one to an understanding of the terms used in the usual refiners list. These are rather serious omissions which one would not expect to find in a book which deals in such great detail with many matters of much less importance. The proportion of space given to the various subjects is not adjusted with a view to the importance of the subjects. Saponifiable oils receive much more attention than mineral oils, though at the present time by far the bulk of lubrication is effected by means of mineral oils, or of mixtures consisting mainly of mineral oils.

Sections dealing with the physical, mechanical and chemical testing of lubricants are very detailed and deal adequately with the subject. A full description of both American (A.S.T.M.) and British (Institution of Petroleum Technologists) methods of analysis is given. The subject of oxidation is not given the amount of space which its importance warrants. All recent work on the tendency to oxidise shown by oils of various bases when subjected to oxidation tests, such as the Michie Sludge test and the Airboard Oxidation test, should undoubtedly have received consideration.

The mechanical testing and the results of various frictional tests are fully explained.

The mechanical appliances used for lubrication, such as drip feed lubricators and pump lubricators receive a great deal of attention and a great deal of space is given to this subject which might have been more profitably employed in strengthening some of the weaker sections of the book.

Bearing design and the composition of bearing metals is the subject of a very clear and well prepared chapter, which is undoubtedly of great value.

A very inadequate section deals with the lubrication of engines and machines. This section is not entirely in line with modern practice for lubrication and gives one only a very poor idea of the problems encountered in lubrication of the machines in question. In a book which gives over 600 pages to the theory and practice of lubrication, it is surprising to find turbine lubrication dealt with in less than one-third of a page, motor cars dealt with in less than one-third of a page, kerosine engines and aircraft engines dealt with in two lines and other machines dealt with with the same extreme brevity.

No reference is made to the use of double purpose lubricants for steam lorries, whilst the very important troubles caused by the oxidation of lubricants on various types of internal combustion engines is not mentioned.

The book is much stronger on the theoretical side than it is on the practical side and there is no doubt that the amount of space given to the various problems of lubrication has been very unevenly distributed. Nevertheless the book is of great value and contains a great deal of exceedingly useful information.

HAROLD MOORE.